

THESIS FOR THE DEGREE OF DOCTOR OF MEDICINE,

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REHABILITATION OF FRACTURES OF THE TIBIA AND FIBULA

A Study of the Restoration of Function following
Fractures involving the Tibial and Fibular Shafts
and the Ankle Joint.

by

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P R E F A C E

The field work for this thesis was undertaken during my tour of duty as a medical officer at the Royal Air Force Rehabilitation Unit (M.R.U.) at Chessington, Surrey. My original intention had been to investigate the effect of various physiotherapy techniques during the rehabilitation of patients with fractures of the tibia and fibula. This proved difficult to put into practice, as the basic knowledge of the functional anatomy following injury to the lower leg and ankle is only superficially outlined in the literature. The first part of this thesis is therefore a study of the factors which affect the return of function after removal of the plaster cast. The factors assessed included the type of fracture, method of fixation, the duration of immobilization and the effect of group exercises in plaster. The classification of ankle fractures adopted by surgeons referring patients to the centre, was found to be inadequate for grouping patients according to their progress during rehabilitation, as well as for indicating the pathology and mechanism of the fracture. A classification has been adopted which emphasizes these features.

In the second part of the thesis the mobilization period was investigated. The ability to perform progressive tests of calf muscle function was found to be a more accurate indication of the progress of patients than measurement of joint range. Contrary to current opinion I was able to show that patients treated at the centre in plaster did not make a significantly more rapid recovery than those patients, who arrived for treatment during the first two to three weeks after removal of the plaster. Further delay in arrival, however, resulted in very slow recovery. The immediate post-plaster period was found to be the most important stage in the rehabilitation of both diaphyseal and malleolar fractures. My personal series of patients recovered significantly more rapidly during this stage than a control series, constructed by retrospective analysis of the case notes of patients who had been treated at the centre immediately prior to my own group. This difference was attributed to different physiotherapy techniques employed in the two series, resulting in more effective control of oedema in the first group.

I have also given my reasons for considering that the disturbances resulting from immobilization of fractures in plaster of Paris are primarily reflex in character rather than due to disuse as commonly believed. Certain physiotherapy techniques may act by reducing the reflex response, and appear to be worth investigating further in controlled trials.

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INTRODUCTION

1. THE REPAIR OF FRACTURES AND SOFT TISSUES FOLLOWING INJURY.

The repair of bone and the effects of injury on the adjacent soft tissues depend on the maintenance of a balance between the two conflicting principles of rest and movement. Repair of a fracture will occur most rapidly if the bone ends are accurately aligned and firmly fixed until union is sound. Conversely, union may be delayed, or the fracture may fail to unite, if movement is allowed to take place at the fracture site. In particular, rotational and shearing strains encourage the formation of cartilage and fibrous tissue parallel to the plane of movement, so that reossification results in the formation of a bony plaque along the surface of the fractured bone ends (Watson-Jones and Roberts, 1934; Watson-Jones, 1952). The histopathological processes which underlie these observations have been detailed by Starr (1947). In essence, bone repair depends on the maintenance of an intact system of blood vessels, around which a profuse cellular reaction takes place. In the early stages callus, composed principally of fibroblasts, fibrocartilage and collagen fibres, is formed from the endosteum, and it is also laid down in the region where the detached periosteum joins the cortex some distance from the fracture site. This process is followed by ossification in membrane, resulting in a bridge of primary bone across the gap between the fragments. In areas where the blood supply is poor, hyaline and fibrous cartilage masses are formed, which may become calcified. Fibrocartilage deposition normally occurs around the cancellous bone ends and subperiosteally, but it may also occur in the interfragmentary gap, if movement between the bone ends results in reduction of blood supply from tearing of blood vessels. Union is therefore delayed until the avascular cartilage masses are invaded by osteogenic fronts from the interfragmentary bridge and detached periosteum.

In practice, it is not possible to ensure firm fixation of a fracture without limiting joint movement and muscle action to a degree which varies with the method of treatment chosen. The changes, which occur in the soft tissues in the neighbourhood of a fracture, result in muscle wasting and the formation of serofibrinous exudates in the form of oedema and joint effusions. The formation of intramuscular and intracapsular adhesions, which follow the deposition of serofibrinous exudates, may exert a prolonged influence on the rate of recovery from injury and may even lead to permanent disability.

Muscle wasting and exudate formation are interlinked in that both are caused, partly by disuse as a consequence of immobilization, and partly by reflex nervous and neurovascular disturbances (Harding, 1929; Casten and Betcher, 1955). It has also been suggested that associated or antecedent phlebothrombosis may sometimes be responsible for these sequelae (Oschner and Landry, 1952).

The effects of splinting have been placed on a quantitative basis by studies of associated biochemical changes. Even in the absence of injury, increased urinary excretion of nitrogen and calcium have been demonstrated. Deitrick, Whedon and Shorr (1948) immobilized four healthy young men for six to seven weeks in bed in bivalved plaster casts extending from the toes to the umbilicus. During this period between 30 and 84 gm. of nitrogen were lost in the urine. These authors arrived at the same conclusion as Guthbertson (1929, 1930) that the nitrogen-sulphur ratios of the excess urinary products suggested that muscle protein katabolism was the source of the loss. Thus, the nitrogen loss would be equivalent to about 4 lb. (1.7 kgm.) of muscle. Calcium excretion also reached about double the normal rate after one month's immobilization. Parallel to these changes the strength of the calf muscles diminished by approximately 20 per cent. as recorded by an ergometer. The girth of the calf and thigh muscles was reduced by approximately 10 per cent. The original levels were not regained until some five to six weeks had elapsed following removal of the plaster casts, in spite of an organised programme of exercises. Circulatory changes were studied by means of a tilting bed, the foot of which was lowered to 65° for periods of 20 minutes. The patients were temporarily removed from the plaster casts for this test. After one week's immobilization all subjects developed a tendency to faint in this position, but there was considerable variation in the time required. In one subject the site of venous stasis was traced to the legs, since it was found that the tendency to fainting was completely abolished by binding the legs from the toes to the groins, but not by applying an abdominal binder. At the end of the immobilization period all subjects developed purpuric haemorrhages in the feet on tilting. These experiments were extended by Deitrick (1948), who was able to reduce the extent of these changes in three normal volunteers. The subjects were immobilized on an oscillating bed for 8 to 20 hours per day for five weeks. Urinary calcium excretion was halved in comparison with that which occurred with a fixed bed; there was a small reduction in nitrogen loss, but the circulatory changes were much less marked and purpuric

haemorrhages were not observed. Wyse and Patee (1954) found that the tilting bed was ineffective in reversing the rather more severe changes in paraplegic patients. These authors conclude that, in non-paralysed patients, the beneficial effects of the tilting bed are due to slight muscle contractions when the weight is borne on the heels, rather than to the direct effects of a circulatory response in the lower extremities or weightbearing through the long bones.

In patients who had been splinted as the result of fractures or bone operations, the urinary excretion of calcium and nitrogen was found to be greater than after splinting normal limbs (Cuthbertson, 1929, 1930). An injury such as a dislocation of an ankle produced as great a disturbance of metabolism as fractures of both bones of the legs (Cuthbertson, 1932). These metabolic changes were confirmed by Howard *et al.* (1944, 1945). Calcium excretion reaches a peak level, which is nearly three times normal, about a month after injury and remains elevated for 30 to 60 days or until mobilization, if this is commenced earlier. Loss of nitrogen was greater following fractures and osteotomies than after non-osseous injuries of comparable severity.

The question arises as to the extent to which these observations are applicable in the present investigation, in which the patients were ambulatory while immobilized in plaster. The oscillating bed was designed to imitate ambulation, while the patient was still confined to bed, and it seems probable that similar changes occur in ambulatory patients. Cuthbertson (1942) suggested that metabolic disturbances after fractures were due to several factors, such as disuse atrophy, loss of muscle substance as a result of trauma, reflex wasting, and autolysis, as well as a generalized increase in metabolism to meet the enhanced metabolism of the repair process. Reflex muscle wasting was first studied in animals by Harding (1929), who demonstrated that posterior nerve root section prevented the wasting which follows production of experimental arthritis. A further contribution to the understanding of reflex disturbances has been provided by the study of certain patients who exhibit excessive reflex trophic and vasomotor changes following trauma. Casten and Betcher (1955) have recently reviewed the problem of reflex sympathetic dystrophy, and have shown that, although there were considerable differences between individual patients, it was possible to divide the clinical material into three grades of increasing severity. Some of the features described in the mildest grade were similar to those seen in the normal subjects immobilized in plaster by Deitrick. In these experiments,

the vasomotor response was particularly variable. The reflex dystrophy syndrome may be due to either (a) an excessive normal response to injury, or (b) a completely abnormal reaction, as the result of an unusual pattern of pain sensation and response, effective either at the spinal cord level (internuncial pool) or as high as cerebral levels of pain integration. Watson-Jones (1952) described the condition as a post-traumatic osteoporosis, which he regarded as an extreme form of disuse atrophy. Böhler (1935) remarked that it is particularly likely to occur when ankle fractures are treated in the early stages by passive movements and massage. Such treatment is usually painful. Consequently the limb is not used. Relief of pain by immobilization in plaster allows the patient to use the limb more normally, and the process of bone atrophy and muscle wasting is reversed. There is no doubt, however, that in many cases sympathetic ganglion block or sympathectomy is successful in alleviating symptoms, possibly by interrupting special afferent sympathetic nerves conducting pain stimuli (Bingham, 1948). But it is equally important to prevent these stimuli arising. Special attention has been paid to these problems in the present study.

No method of treatment has yet reached the theoretical ideal of complete immobilization of the fracture, while allowing normal joint and muscle activity. Historically, the pendulum has continued to swing between rigid immobilization with loss of joint and muscle function, and minimal immobilization in which emphasis is placed on treatment of muscles and joints at the risk of delayed union or non-union of the fracture.

2. THE SURGICAL TREATMENT AND REHABILITATION OF FRACTURES.

Rehabilitation has been defined as the process of restoring a disabled person to a condition in which he is able as early as possible to resume a normal life. The term should be confined to medical or surgical treatment designed to restore physical and mental functions and to the process of reconditioning necessary to enable a patient to take up employment or vocational training (Report of the Committee of Inquiry on the Rehabilitation of Disabled Persons, 1956). As applied to the treatment of fractures, the present trend in this country is for the orthopaedic surgeon to be directly responsible for the initial surgical stage. Later, when the emphasis is on the restoration of function, he supervises the work of a team of physiotherapists, occupational therapists and

remedial gymnasts. In some centres, including the Royal Air Force Medical Rehabilitation Units, the team includes physicians, who are primarily interested in the treatment of disorders of the locomotor system. This practice has resulted in the intensive study of problems arising from the rehabilitation of injuries. A background for this study is provided by experience of similar difficulties in the treatment of arthritic and neurological conditions.

In the next section I have outlined the main stages in the history of the surgical treatment of fractures. This is intended to serve as an introduction in subsequent sections to the more detailed analysis of the rehabilitation services in civilian life and in the Armed Forces.

3. THE HISTORICAL BASIS OF THE SURGICAL TREATMENT OF FRACTURES.

The use of splints to immobilize broken limbs probably dates from prehistoric times. Elliot Smith (1908) examined over 100 skeletons of Ancient Egyptians, who had sustained fractures of the forearm bones, and found only a few fractures with residual displacement. There was evidence to suggest that these fractures had been treated in multiple bark splints, lined with straw or coarse grass, and moulded to the contour of the limb. However, a compound fracture of the femur had been inadequately immobilized with wooden splints wrapped in linen. The Hearst Medical Papyrus contains prescriptions to be used in the treatment of fractures; materials such as honey, flour and gum were to be incorporated with cloth in bandages. These substances hardened to form casts in the same manner as modern plasters (Leake et al., 1953). Hippocrates (c.350 B.C.) used linen soaked in cerate and resin for splinting, a technique which he learned in Egypt. Both Hippocrates and the Hindu surgeon, Susruta (c.400 B.C.) were familiar with the use of traction to reduce fractures.

From the rather scanty written records available little progress appears to have been made in the treatment of fractures until the beginning of the 18th century. At this time wooden splints were used, one of which resembled the leg frame introduced by Böhler. Bandages, stiffened with white of egg, flour, starch or sometimes clay-like minerals were employed (Monro, 1935). It is evident that plaster-of-Paris casts were used to immobilize fractures in Arabia during this century, a custom which may have dated from a much earlier period. However, it was not until the earlier part of the 19th century that plaster-of-Paris was used in Western Europe, being poured

into a wooden box, which encased the limb. The box could be dismantled when the plaster had set. The forerunner of the modern plaster bandage was introduced by Mathijsen (1852), who rubbed plaster-of-Paris into strips of coarse-meshed cotton, which were loosely rolled into bandages.

Percival Pott (1769) was the first to insist on the necessity of splinting joints above and below fractures. Many later surgeons have disagreed with this procedure on the grounds that the distal joints, in particular, are liable to become very stiff with prolonged immobilization. This tendency appears to have become more marked after the introduction of plaster casts. This may have been due to the fact that the early plaster casts were heavy, so that in the case of fractures of the lower limbs patients had often to spend several weeks in bed. The introduction by

Hugh Owen Thomas in 1867 of his wellknown splint and walking caliper provided a means of overcoming this difficulty. Although he demonstrated that immobilization of a healthy joint does not lead to ankylosis, he was severe in his condemnation of the rigid fixation provided by plaster-of-Paris casts, which he considered delayed union and left restoration of function to chance. This reaction to the extensive and rigid immobilization of the period was carried a stage further by Lucas-Championnière, who abandoned the use of splints except in the treatment of some fractures of the tibia and fibula. He relied on massage and passive movements, which he claimed reduced the fracture and promoted union. He denied that absolute lack of movement was the most favourable condition for the repair of bone (Lucas-Championnière, 1907). On the contrary, animal experiments led him to believe that a certain amount of movement of the fractured bone ends accelerates the formation of bone. The number of ununited fractures or deformed limbs produced by this method was probably high, but on the other hand rigid splinting often resulted in permanent incapacity due to muscle fibrosis and joint adhesions. When the results of treatment of 3000 fractures were investigated by a Committee set up by the British Medical Association in 1912, malunion was found to have occurred in 40 per cent. and a poor functional results was a frequent finding in the remainder.

Walking plasters were introduced by Krause in 1887. A boot was laced over the plaster when walking outside. Korsch (1893) used a U-shaped metal stirrup for transmitting the weight to the ground, a method which was popularized by Böhler in the 1914-18 War. During this period, a number of surgeons preferred to leave the ankle joint free from plaster,

and it was a common practice to immobilize fractures of the tibia and fibula for periods as short as six weeks. Böhler (1935) vigorously condemned inadequate and insufficiently prolonged splinting. He considered that prolonged periods of disability following plaster immobilization were due to removal of splinting before union of the fracture was firm, resulting in redisplacement and swelling of the affected limb. He preferred closed methods of reduction, and also maintained reduction of unstable fractures of the shafts of the tibia and fibula by means of skeletal traction for the first 3 to 4 weeks. Thereafter, patients were encouraged to walk as much as possible in a walking plaster. He recommended that these fractures should be kept in plaster for at least 8 to 10 weeks. He stressed the importance of toe exercises in plaster, as well as active leg exercises, including walking, in preference to massage and passive movements after the plaster cast had been removed.

At the end of the last century Lane introduced the use of metal plates to aid fixation of unstable fractures in particular. In fractures of the tibial shaft this technique has been developed to its fullest extent by Blockley (1956), who used special care to ensure that the plate imparted rigid fixation to the fracture. After operation, the fracture was protected by a posterior plaster shell, which was removed twice daily for knee and ankle exercises. Weightbearing was not allowed until eight weeks after operation, when in the majority of patients the splint could be removed. In two-thirds of the patients, full weightbearing without support was possible by the end of three months. A further attempt to reduce the necessity for prolonged external splinting was the introduction of the intramedullary nail by Küntscher in 1940. When applied to fractures of the shaft of the tibia, this method has been developed more extensively in America than elsewhere in the last 10 years. The method of Von Saal (1952), using two U-shaped nails, allowed early weightbearing, in many cases within a week of operation, without any external support other than an elastic bandage. Normal activity could be resumed between 6 weeks and 3 months after injury, and there was virtually no muscle wasting. In theory these methods of fixation approach the ideal, but their limitations have not been assessed. The U nails were claimed to provide better fixation than any other form of internal splint previously used. Böhler (1949) compared the results of his own conservative methods with those obtained with internal fixation of fractures of the shaft of the tibia by means of Küntscher's nail. Nailing proved less satisfactory, since

it did not eliminate the need for external splinting and increased the incidence of delayed union and non-union. Watson-Jones also emphasized the need for adequate fixation until union was firm, and stressed the importance of active exercises both in and out of plaster. However, he condemned the use of skeletal traction in fractures of the tibial shaft for longer than a few days; otherwise, union was delayed. He preferred to fix unstable fractures with a plate or screw (Watson-Jones and Coltart, 1943; Watson-Jones, 1952). The use of skeletal traction has also been criticized by Albert (1944), who showed that the incidence of delayed union was doubled when skeletal traction was continued for more than a few days.

In general, conservative treatment is the method of choice in this country at present. Open reduction is confined mainly to the fixation of unstable fractures and to the treatment of established non-union. The continuation of skeletal traction for several weeks has not yet been completely abandoned.

4. THE DEVELOPMENT OF REHABILITATION SERVICES FOR FRACTURES IN CIVILIAN LIFE.

It is natural for a patient to respond to injury by using the affected part as little as possible. This tendency may be increased if the injured limb is encased in plaster-of-Paris. It has been customary to encourage the patients to remain as active as the nature of the fracture will allow, and in many centres treatment has been organized with this objective. The present tendency is to consider such treatment in two phases - a phase of maintenance of function during the period of immobilization, followed by a phase of restoration of function (Zinovieff, 1954). This concept has developed slowly. The treatment of fractures in this country was surveyed in the Report of the Committee of the British Medical Association on Fractures (1935). At this time organised treatment, aimed at increasing the patient's functional capabilities, was carried out only in a few special fracture clinics and limited to the recovery phase. The Joint Committee of the British Medical Association and Trades Union Congress on the Rehabilitation of the Injured (1937) considered a scheme for treatment of fractures in three phases. Surgical treatment should be followed by a period of physiotherapy, conducted in the appropriate department of the hospital. This should immediately be succeeded by a period of rehabilitation, which was defined as "occupational and recreational activity involving the use of muscles and joints formerly immobilized,

culminating in a phase of preparation for the occupation previously undertaken by the individual, or in certain circumstances, the retraining of an injured or disabled workman for a new occupation." Rehabilitation was conceived as a period of more active convalescence after surgery and physiotherapy had finished. A few centres had already been established for this type of reconditioning.

The Astley Ainslie Institution had been opened in Edinburgh in 1923 as a hospital for the convalescence of both medical and surgical patients. The average length of stay of fracture cases (about 20 weeks) admitted to the Institution in the years 1931 to 1936 was found to be twice that of all other patients. Prolonged hospital treatment was considered to be essential for the more severe types of injury (Cunningham, 1938). In 1924, Moore commenced the rehabilitation of chronic traumatic patients at the London Midland and Scottish Railway Hospital at Crewe, and by 1932, had treated 165 patients. On discharge 115 patients (70 per cent.) were considered to have made sufficient recovery to return to their pre-accident employment. The mean rehabilitation period was 17 days, and no patient stayed longer than two months, even though over half of these patients had been incapacitated over six months. The remaining 50 patients (30 per cent. of the total) were considered unlikely to be fit to return to their former employment. A further 5 per cent. of those patients, who appeared to have been successfully rehabilitated, failed to take up employment. A striking feature of Moore's analysis was the high incidence of psychological disturbances. He considered 10 per cent. of his patients to be work-shy or malingerers, and in a further 17 per cent. the surgical condition per se appeared to be almost negligible but was a genuine and serious disability in the patient's mind. In the majority of cases his patients were not receiving active treatment immediately before admission, and function was stationary. Moore (1933) went on to make a number of observations which have been accepted as the basic features of successful traumatic rehabilitation today, namely:

Much of the passive physiotherapy should be scrapped. More attention should be paid to the active co-operation of the patient in his treatment, which should be daily and intensive. The place of physiotherapy was within the active rehabilitation programme rather than as a preliminary stage. The

mental side of the patient should be studied and treated accordingly. Records should be kept of clinical progress made and stresses sustained. Finally "no case should be discharged from treatment until maximum restoration of function has been established."

Watson-Jones (1933) remarked, on discussing this paper, that "the object of treatment must always be a limb which cannot be distinguished from normal We cannot be satisfied with residual deformity, because the deformity is not the one which impairs function; the workman must be able to see for himself that the functional result is good."

The effect of segregating the treatment of fractures in specially organized clinics in certain hospitals was discussed by the Committee of the B.M.A. in the Report on Fractures (1935). At this time these clinics were in existence at the Royal Free Hospital in London, the Liverpool Royal Infirmary, and at the Ancoats Hospital, Manchester, where all fracture cases were under the direct supervision of orthopaedic surgeons. The average disability period for adults treated in the organized clinics in Liverpool and Manchester was compared with that for patients treated either in general hospitals not equipped with special clinics or by general practitioners. For all fractures the average duration of incapacity per patient was seven months less in the organized clinic group (a loss of 168 working years for the 276 patients studied). The Committee recommended the setting up of special fracture clinics, in which the fracture clinic staff was responsible for physiotherapy and all remedial measures. Passive physiotherapy was condemned. The provision of rehabilitation centres to bridge the gap between the completion of remedial exercises and the starting of heavy manual work was also suggested. One centre should be established in each industrial area. In some areas these centres might be developed from the training workshops already associated with orthopaedic hospitals; in others, a convalescent home or unoccupied mansion might be utilized. Residential or day accommodation should be provided according to the needs of the area with treatment facilities consisting of workshops of a simple nature, gymnasium and playing fields. Middleton (1936) also recommended the setting up of similar centres for the rehabilitation of the industrial worker, with special reference to South East Scotland. He favoured a unit of 100 beds with treatment based on graduated occupational therapy. This

theme was developed further in the Memorandum of the Joint Committee of the B.M.A. and T.U.C. (1937), referred to above. It was suggested that about 25 per cent. of the patients attending an organized fracture clinic required rehabilitation at a centre, and an average duration of treatment of four weeks should be assumed. The Committee stressed that in many patients the aim of treatment is to create a new mental outlook away from the harmful home influence of well-meaning but over-indulgent relatives. The importance of close contact with the parent fracture clinic was emphasized, so that problems arising during treatment, and fitness for work can be discussed with the surgeon in charge of the fracture clinic. It was felt that the superintendent in charge of the centre should be a medical man with some knowledge of orthopaedic and traumatic surgery. It was not necessary for him to be an expert surgeon, but his selection should depend on his knowledge of men and his experience of the trades and occupations in the area. If he took part in representative occupations for short periods, it would enable him to become familiar with the amount and type of exercise required in different jobs and to know when the workman had recovered sufficiently to resume work.

The Delevigne Committee in their Final Report on Rehabilitation after Accidents (1939) acknowledged the importance of expert treatment and supervision of fractures in special clinics until working capacity was fully restored. They were more cautious in recommendations for the setting up of special rehabilitation centres. It was considered that the establishment of experimental rehabilitation centres in connection with fracture clinics was desirable; but insufficient data were available to determine the nature or extent of the requirements in each area, until the effects of adequate physiotherapy and remedial exercises at the special clinics had been assessed. An alternative scheme was proposed for those patients who required a period of reconditioning, either because of the heavy nature of their normal work or on account of residual functional disability following discharge from hospital. Reconditioning should take place as far as possible within the industry in which the patient was employed. This could be in the form of graduated work, but, if this was impracticable, facilities for remedial exercises should be made available. These facilities could be provided by individual firms, or at centres under the control of voluntary societies, or within the Government's National Fitness Movement. Two centres under voluntary control were already in existence near Motherwell

under a scheme started by the Lanarkshire Orthopaedic Association in 1935. These were outpatient clinics and not bound to any particular hospital, so that continuity of control was lost (Miller, 1942).

The development of civilian rehabilitation services, during and since the last war, has followed the pattern suggested in the Delevigne Report. Arrangements have been made for the provision of graduated work within industry. Rehabilitation centres have been set up within industries, for example, miner's rehabilitation centres, or close to factory workshops, such as the British Railways retraining workshop at Swindon and the Vauxhall scheme. The remarkable success of the Vauxhall scheme is due to the close co-operation between the local orthopaedic service and the factory so that continuity of treatment is maintained. Only the minimal time off work is allowed for initial treatment of injuries, the remedial phase taking place in the factory retraining shop, where machines are adapted for use in such a way that the injured part is re-educated. Where necessary, physiotherapy is also given during working hours. For smaller factories in the area a retraining workshop is provided within the grounds of the local orthopaedic centre. A rehabilitation superintendent is responsible, not only for the supervision of the workshops, but also for job analysis in all accident cases, and for surveying the patients' working environment to ensure a graduated return to full employment (Plewes *et al.*, 1948). For the reconditioning of fracture cases the Government Industrial Rehabilitation Centres, initiated by the Ministry of Labour in 1944, have been ^{less} successful, mainly because continuity of treatment has been lost.

The Piercy Committee in their Report on the Rehabilitation, Training and Resettlement of Disabled Persons (1956) considered that the medical and industrial rehabilitation services had not grown up together on a co-ordinated plan, thus retarding day-to-day co-operation. Although this separate development may have been accidental, they felt that it may have stemmed from the Report of the Tomlinson Committee on the Rehabilitation and Resettlement of Disabled Persons (1943), in which medical rehabilitation and post-hospital rehabilitation was sharply demarcated. This distinction can, however, be traced back to the Report of the Delevigne Committee (1939), as outlined above. The Piercy Committee recommended a closer co-operation between the hospital and industrial rehabilitation services, and suggested the setting up of combined centres, in which facilities for physiotherapy and remedial gymnastics, as

well as an industrial workshop, would be available on the same site. This principle has already been put into practice in the operation of the Royal Air Force Medical Rehabilitation Units.

5. THE DEVELOPMENT OF REHABILITATION SERVICES FOR FRACTURES IN THE ARMED FORCES.

War frequently provides a stimulus to the practical application of ideas. Some of these ideas are developed further in peacetime while others lie dormant. The segregation of fracture cases in hospital appears to have been initiated in No. 8 Stationary Hospital, Wimereux, France in 1915. Meanwhile in this country Sir Robert Jones was responsible for the pioneering of a large-scale military rehabilitation programme with the aid of physical training instructors. As has been seen above, both these ideas were put into practice on a limited scale in civilian life between the two World Wars. When the Second World War broke out, the shortage of highly skilled personnel, in the Royal Air Force in particular, made it imperative that the convalescent period should be reduced to a minimum. Rehabilitation centres were organized on lines suggested by the B.M.A. Committee on Fractures in their Report (1935). Initially, two types of centre were established. Houlding (1941) described a rehabilitation centre set up within a Service Hospital for treatment of injured air crews. The staff consisted of a medical officer, physical fitness officer, Sergeant N.C.O. and three masseuses. The facilities consisted of a single gymnasium, a four-cubicle physiotherapy department and a rest centre. The emphasis in treatment was placed on active exercises, and the patients were divided into three groups according to the grade of activity permitted. For plaster and similar cases a programme of two sessions per day of special remedial games (mostly non-weightbearing) was arranged under the supervision of a masseuse. Later, when the patient joined a "nearly fit" or "fit" class, the remedial periods were reduced, and more time was devoted to swimming and sport. Physiotherapy was of value in selected cases, but the masseuses were employed primarily to supervise remedial exercises. This was found to be more satisfactory than using the services of a specially trained physical training instructor. Houlding recorded that 16 per cent. more patients were discharged to flying duties during the first six months this centre was opened than during the previous six months. However, it soon became apparent that the hospital rehabilitation centre was less successful than those established at some distance from fracture hospitals, mainly due to difficulties in providing the right atmosphere. Sir Reginald Watson-Jones (1941) was mainly instrumental in the

establishment of this second type of centre, and was responsible for setting up a rehabilitation programme in hospital wards. At first, patients were chosen to lead exercises in wards, but later specially trained nursing orderlies supervised the hospital physical and recreational activities. The importance of the type of treatment, which these rehabilitation orderlies supervised, has become generally recognized, especially the hourly repetitive exercises and the teaching of the correct method of walking in plaster. At the time of this survey, hospital treatment was supervised by Service-trained physiotherapists. In general, patients were considered fit for transfer to a rehabilitation centre as soon as their wounds were healed or fractures stabilized.

6. THE ORGANIZATION OF ROYAL AIR FORCE REHABILITATION CENTRES

At the end of the late war, the Royal Air Force Medical Rehabilitation Centres were reorganized according to the requirements of peace-time needs. There was no longer the urgency to get patients fit as quickly as possible. However, when patients were sent home on sick leave, it was apparent that the standard of the local civilian rehabilitation services could not be guaranteed. In addition, the period of convalescence tended to be prolonged because, as the patient became accustomed once again to civilian life, re-adaptation to Service conditions became more difficult. Indeed, the convalescence of a National Service sirman was sometimes lengthened until his period of Service had been completed. At a time when National Service men formed the core of the Royal Air Force rapid rehabilitation again became important; the value of previous training might be completely lost through long absence.

Three Medical Rehabilitation Units were established, each with a slightly different emphasis according to the occupation of the personnel under treatment. One unit was based on a country mansion and catered for officers and air crews. The other two units were housed in former balloon barrage stations where suitably heated hangars were available for conversion to gymnasiums. The second unit was designed to rehabilitate technical personnel and was equipped with workshops. The third unit, for 250 non-technical personnel, was set up at Chessington in Surrey.

The units were run on similar lines to the stations to which the patients were accustomed, although, in place of normal

duties, they took part in a full day's programme of remedial exercises, games and physiotherapy. They looked after their own billets, but catering was in the hands of a permanent staff. The unit provided the necessary stepping stone between hospital conditions and the normal R.A.F. station routine. The cost per patient was low in comparison with that of hospital treatment. Over 80 per cent. of the patients were suffering from orthopaedic disabilities. Medical treatment was supervised by medical officers, in the approximate ratio suggested originally by Sir Reginald Watson-Jones (1941), namely, one medical officer and one physiotherapist to 50 patients. The establishment of physical training instructors was increased to three per 50 patients. Organization of the physical training programme was in the hands of the Physical Fitness Officer, who worked closely in conjunction with the medical officers. He was also responsible for discipline and welfare, but more recently was assisted by a Welfare Officer. It has been our experience that the maintenance of discipline should not be undertaken by medical officers; otherwise, it became more difficult to obtain the patient's co-operation in unravelling psychological complications, which may be delaying rehabilitation.

On arrival at the unit, each patient was seen by one of the medical officers, and the treatment programme was arranged. Patients were grouped into various classes according to the anatomical site of their disability or the stage in their recovery. At Chessington there were 14 classes at the time of this survey. A patient who had sustained a fracture of the tibia or fibula or an ankle injury would normally be allocated to one of three leg classes, and would remain under the supervision of the same medical officer. The Static Legs class followed a programme of remedial exercises and games, which were predominantly non-weight bearing and static in nature, with the emphasis on toe exercises and quadriceps development. This regime was suitable for those patients still in plaster, and also for those out of plaster until sticks and crutches could be discarded. Attention was therefore paid to the correct methods of walking in plaster and using crutches or sticks. This class used a separate small gymnasium adjoining one of the physiotherapy departments, so that the more active patients did not come to grief amongst the crutches. Patients remained in this class until they could walk with almost even paces without the use of sticks, and were then ready to move on to the Early Legs class. The objective in this class was to develop spring in walking, leading up to the early stages of running and jumping. The

key to success at this stage was the development of increased power of the calf muscles. In addition, the patient had to learn to co-ordinate these muscles in the basic reflex patterns, on which re-education of normal activities depends. Mobilization of the ankle and foot would appear to be less important. Nicoll (1941) also believed that diminished mobility with full muscle power gives a better functional result than full mobility and diminished power.

Finally, in the Late Legs class the patient regained his ability to run normally and to take part in all games short of competitive sport. The programme included tests of agility, walking over rough ground, boxwork and running. Before discharge, patients were expected to be able to cover a five mile cross-country course. The stage at which patients were discharged varied according to the duties required by their trades. Flight Lieutenant Houlding (1941) discharged his patients when the calf muscles were powerful enough to enable them to rise on their toes without assistance. Most of my patients reached this stage in the Early Legs class, but it seemed worth while to allow them a few extra days in the Late Legs class to gain confidence from the agility tests. In certain cases prolonged treatment in this class was advisable. In this category were patients in such trades as physical training instructors, and also men from the Royal Navy and Royal Marines who might be required to climb ladders on a rolling ship.

It was sometimes necessary for some of these patients to spend a part or all of the day's treatment in one of the other classes. If marked wasting or weakness of the quadriceps muscle occurred, more concentrated treatment was available in the Static Quadriceps or one of the Knee classes, which catered predominantly for cartilage injuries. If severe foot complications were present, some of the patients spent a short period in the Feet class. All classes followed a basic daily routine consisting of three hours' specific remedial and walking exercises and three hours' organized remedial games.

Physiotherapy was not considered to be an essential part of the treatment programme. Any advantage to be gained by attending the physiotherapy department had to be balanced against the time lost from remedial exercises or games in the class. However, in many cases it was

considered to be of sufficient value to provide full time employment for six civilian physiotherapists. The type of treatment selected in this survey will be discussed in a later section.

Remedial Occupational Therapy was available, but found to be of little value in treating leg injuries.

The unit had its own plaster room and X-ray department, so that plasters could be changed or removed without the patient having to be returned to the orthopaedic centre which had referred him. For simple fractures the decision to change or remove a plaster cast was made by the medical officer in charge of the case, following instructions given in the case notes of the patients when they were referred. In addition, a fortnightly visit by one of the senior orthopaedic specialists to the centre ensured that an orthopaedic opinion was available in solving the more difficult problems. On discharge from the centre, the patient was boarded for review in two or three months by the orthopaedic specialist, who had referred him, so that an assessment of his ability to cope with his Service duties could then be made. Several of these specialists visited the unit and discussed the progress of their patients while under treatment.

The importance of a unified scheme for treatment of fractures has been stressed above. Mention must be made of the part played by R.A.F. orthopaedic surgeons, whose helpful advice with individual problems, and guidance in organization have made for the success of treatment by rehabilitation.

7. CLASSIFICATION OF FRACTURES OF THE TIBIA AND FIBULA.

The classification of fractures of the shafts of the tibia and fibula is straightforward. Most authors adopt a similar method when assessing the results of treatment. Single and compound fractures are usually sub-divided according to the situation of the tibial fracture in the upper, middle or lower third of the bone. Occasionally fractures of the tibia alone are analysed separately; the majority of these fractures unite more rapidly and are more easily rehabilitated than when both bones are broken.

Classification of fractures of the ankle is still the subject of considerable controversy. Historical surveys

of the development of our knowledge of the mechanism and diagnosis of ankle injuries have recently been made by Lauge (1948) and Bonnin (1950). These surveys have an important bearing on the recognition of the presence of ligamentous tears complicating individual fractures of the ankle. Untreated ligamentous lesions may result in the ankle becoming painful and unstable when mobilization is attempted. Each type of "ligamentous ankle fracture" (Lauge) requires a particular method of reduction and period of immobilization in a non-weight bearing or walking plaster. If these additional lesions are overlooked, failure of adequate reduction and fixation may lead to prolonged periods of physiotherapy even in the absence of marked bone displacement. "Six weeks in plaster following a Pott's Fracture" should be a statement of historical interest, but is, as we shall see, still a common rule of thumb. The historical background is essential to the understanding of the mechanism of ankle fractures and of the degree of damage to ligaments. First, it is necessary to define the terms which I have used to describe movements of the ankle and foot.

Dorsiflexion and Plantar Flexion:- hinge movement of the foot around a transverse axis through the body of the talus. This movement occurs in a plane which corresponds to the plane of the inner surface of the medial malleolus. However, the axis, around which movement occurs, makes an angle of 20 to 30 degrees with the bimalleolar axis between the two most prominent portions of the malleoli (Ashurst, 1922; Bonnin, 1950). The upward movement of the foot, or dorsiflexion, is limited at the ankle joint by contact of the neck of the talus with the anterior margin of the tibia. Additional movements occur at the midtarsal and intertarsal joints, the range of which is partly an individual characteristic and partly dependent on the extent of movement required in everyday use. Similarly, downward movement of the foot, or plantar flexion, is stopped by contact between the posterior process of the upper surface of the body of the talus and the posterior margin of the tibia. Further movement occurs in the joints of the foot.

Abduction:- abnormal movement at the ankle joint allowing the vertical axis of the talus to angulate laterally.

Adduction:- a similar movement to abduction but allowing the vertical axis of the talus to angulate medially. In the normal ankle, adduction of the talus of up to 4 degrees is frequently observed. According to Bonnin, between 5 degrees and 15 degrees of movement can be demonstrated bilaterally in normal ankles of 4 per cent. of men and

5 per cent of women.

Lateral Rotation: - lateral rotation of the foot in a horizontal plane around a vertical axis through the tibia, allowing the hallux to point laterally [Lauge - Hansen (1950) calls this movement eversion].

Medial Rotation: - medial rotation of the foot in a horizontal plane around the same axis allowing the hallux to point medially (Lauge - Hansen: inversion).

These movements have two components. At the tibio-talar joint up to 5 degrees or 6 degrees lateral rotation of the talus relative to the tibia may be observed on dorsiflexion. The rotation is reversed on plantar flexion. This range of movement has been demonstrated during normal walking (University of California Prosthetic Devices Research Project, 1952). But, whenever the foot is placed on the ground, the talus is fixed, and it is the tibia which rotates laterally, so that the distal anterior tibial tubercle approaches the lateral malleolus. On dorsiflexion, however, although the tibia rotates medially on the talus, the resilience of the inferior tibiofibular syndesmosis permits the lateral malleolus to remain with the talus, resulting in lateral rotation of the fibula in relation to the tibia. The range of this movement is considerably increased by sectioning the ligaments of the syndesmosis, which also allows backward displacement of the lateral malleolus (Close, 1956).

The second component occurs mainly at the midtarsal and intertarsal joints. The terms abduction and adduction of the forefoot have been used as synonyms by other workers.

Eversion: - normal outward rotation of the whole foot around a sagittal axis, namely, the longitudinal axis of the foot.

Inversion: - normal inward rotation of the whole foot around a sagittal axis. Both these movements have two components, namely, a posterior component acting at the subtaloid joint, and an anterior rotation movement occurring in the mid-tarsal and intertarsal joints.

Pronation: - combined movement consisting of eversion and lateral rotation of the foot.

Supination: - combined movement of inversion and medial

rotation of the foot. The range of these movements remains the same whether the foot is dorsiflexed or plantar-flexed or adopts a mid-position (Lauge - Hansen, 1950).

A number of small but important movements which occur at the ankle joint are dependent on the resilience of the inferior tibiofibular syndesmosis.

Cranio-caudal movement of the talus: - movement occurring on weightbearing, when the body of the talus moves proximally into the tibiofibular mortise. The upper articular surface of the talus is wedge-shaped, and it was formerly believed that the tibiofibular mortise exerted a firmer grip on the talus on dorsiflexion than on plantar-flexion, so that on weightbearing the foot is converted into a rigid lever (Bonnin). Studies performed in connection with the University of California Prosthetic Devices Research Project (1952) did not, however, reveal any difference in the amount of "play" of the talus during these movements.

Diastasis: - lateral displacement of the fibula from the tibial groove. Displacement of the fibula of up to 1.5 mm. occurs on dorsiflexion of the normal foot. Only when all the ligaments of the syndesmosis have been sectioned is further displacement permitted. Separation of the malleoli by more than about 4 mm. is prevented by tension on medial and lateral ligaments of the ankle, provided these are intact (Close, 1956).

In the literature, many of these terms have been interchanged by different authors, and, in order to avoid confusion, I have transcribed the older terms into their modern equivalents. The account which follows has been based on the extensive surveys of Lauge and Bonnin mentioned above, as well as on those of Ashhurst, who even in 1922 studied 250 articles in the preparation of his paper. My commentary is intended to provide a method of building up by stages the classification of ankle fractures which I have adopted.

It was not until the early eighteenth century that the foundations of our knowledge of ankle injuries were laid. From the days of Ancient Egyptian and Greek Medicine ankle injuries were considered as luxations, and the presence of fractures was ignored. Hippocrates (about 350 B.C.) did, however, mention that fractures of the distal end of

the tibia and fibula might complicate luxations. He regarded the tibia and fibula as the luxating parts which might be displaced inwards, outwards, forwards or backwards. Jean-Louis Petit (1723) considered that the talus and foot were the luxating parts. Recent authors (Close, 1956; Kleiger, 1956) considered the Hippocratic mechanism to be more correct, since the foot is usually fixed on the ground when injury occurs. However, it is more convenient to regard the displacement as that of the talus, since it is this bone which is restored to its normal position on reduction. Heister (1718) was the first writer to stress that outward luxation of the ankle can hardly occur without diastasis or fracture of the lateral malleolus, but Petit, in confirming these observations, stated that fractures of the medial malleolus were found more frequently.

Fractures of the Fibula above the Inferior Tibio-Fibular Ligaments

Towards the end of the eighteenth century more detailed descriptions of ankle injuries appeared. In 1769 Percival Pott described the fracture of the lower end of the fibula, which is produced when the talus is forced into abduction. He mentioned that the fibula breaks within 2 to 3 inches (5.1 to 7.6 cm.) of its lower extremity. He then suggested that "the inferior fractured end of the fibula falls inward towards the tibia", and the lateral malleolus is "turned somewhat outward and upward". In his description and illustration of the fracture Pott does not indicate that this type of fracture is inevitably preceded by at least partial rupture of the ligaments binding the lower end of the fibula to the tibia. He implied that the leverage required to produce this fracture acts around a fulcrum at the lateral margin of the lower articulation of the tibia. The medial ligaments give way subsequently, as the tibia is no longer balanced on the talus and displaced inwards on weightbearing. Ashhurst (1922) pointed out that the lower portion of the fibula involved in this fracture is so closely applied in a groove on the lateral surface of the tibia that it cannot fall inwards in the manner described by Pott, and he took the view that Pott had described a fracture that does not exist. There is, however, a typical, though rare, fracture at the ankle, which corresponds closely enough to the original illustration; even Ashhurst considered it "worthy of being called" Pott's fracture. It is a flexion fracture of the fibula, produced by abduction of the talus, usually $3\frac{1}{4}$ inches (8 cm.) or higher

above the tip of the lateral malleolus, accompanied by fracture of the medial malleolus and by rupture of the tibiofibular ligaments. Bonnin (1950) clearly formulated the mechanical principles of this fracture. He argued that the leverage applied by the foot on forced abduction of the talus acts round a fulcrum at the fracture site. When the structures on the inner aspect of the ankle give way, the fibula bows forward and bends at the level described by Pott and may eventually fracture obliquely. Pott believed that he was describing the most common fracture of the ankle, which has since been shown to be the oblique spiral fracture of the distal end of the fibula produced by lateral rotation of the foot. However, it has been suggested that there is a lateral rotation component in the force required to rupture the inferior tibiofibular ligaments and to produce a fracture of the fibula at the level of Pott's fracture (Lauge - Hansen, 1950). The evidence for this suggestion is that this fracture has been produced experimentally only by lateral rotation of the foot (Huguier, 1848; Hönigschmied, 1877) or by lateral rotation of the pronated foot (Dunand, 1878; Lauge - Hansen, 1950).

To summarize, the presence of a fracture of the fibula, due to indirect violence, above the level of the attachment of the inferior tibiofibular ligaments to the tubercles of the tibia and fibula (i.e. a supratubercular fracture), indicates that at least partial rupture of these ligaments has occurred. In the absence of a fracture of the medial malleolus, rupture of the deltoid ligament is a probable complication. These fractures are potentially very unstable and may require special care in reduction, immobilization and rehabilitation in order to prevent subsequent displacement. The fracture line may be transverse, oblique or of the butterfly type, indicating flexion strain due to abduction of the talus. The oblique fracture usually runs laterally and upwards from the medial surface of the bone. The presence of a helical element in the fracture surfaces is due to lateral rotation strains.

Fractures of the Fibula at the level of the Inferior Tibio-Fibular Ligaments

In 1771 Jean-Pierre David stated that the fibula may fracture just proximal to the lateral malleolus. He believed that the fracture was caused by pressure exercised by the talus against the malleolus, and by the action of the peroneal muscles when the fibula is held back by ligaments.

Dupuytren (1777 - 1835), after describing fractures of the ankle of the same type as Pott's fracture, reported a further group of patients, in whom the fracture line was "situated more distally - $2\frac{1}{2}$ inches (6.4 cm.) or less above the tip of the lateral malleolus ... The foot is turned inward with luxation of the talus outward under the lateral portion of the ankle. The medial edge of the foot turns upward, the lateral downward, and the planta inward." He was the first author to study the mechanism of ankle fractures (c. 1816) by means of experiments on cadavers, in which the foot was fixed in a vice and the leg moved from side to side. He showed that rapid inward movement (adduction of the talus) will result in fracture of the distal end of the lateral malleolus (malleolar fracture). However, he was unable to reproduce in cadavers the fracture of the distal end of the fibula above the malleolus, which he had seen in patients and which resulted in a foot that was supinated and displaced laterally. He thought that both this and Pott's fracture might be produced by forced abduction of the foot. Maisonneuve (1840) conducted further experiments on cadavers, in which the foot was rotated laterally in a horizontal plane, and he produced an oblique spiral fracture of the distal end of the fibula extending up to nearly 2 inches (5.1 cm.) above the tip of the malleolus. He was able to reproduce the peculiar position of the foot which Dupuytren had described in patients, and found that the displacement disappeared when the foot was medially rotated. He was fortunate enough to be able to dissect this fracture soon after its occurrence in a patient, and noted that the fracture line could only be opened up by lateral rotation of the foot. He pointed out that the lateral malleolus is displaced backwards as well as outwards. He also noted that the anterior fibres of the deltoid ligament and anterior capsule were torn, or the medial malleolus fractured, and found that these lesions were always consecutive to the fibular fracture in cadaver experiments.

The oblique spiral fracture of the lower end of the fibula is the commonest fracture of the ankle in males (Lauge - Hansen, 1952). Destot (1911) referred to it as the "Mixed Oblique" fracture, as it involves the fibula both above and below the inferior tibiofibular joint. In the majority of cases the fracture line commences anteriorly at the level of the talotibial articulation, just proximal to the prominent anterior upper border of the lateral malleolus. Its obliquity varies considerably. The posterior tip of the distal fragment may reach as much as $2\frac{1}{4}$ to $3\frac{3}{4}$ inches (6 to 7 cm.)

above the tip of the malleolus. The surface of the proximal fragment looks downwards, laterally and backwards. The fracture line runs between the attachment of the anterior and posterior tibiofibular ligaments to the corresponding anterior and posterior tubercles of the tibia and fibula, and thus may be regarded as being inter-tubercular. Both Ashhurst and Bonnin believed that in most cases these ligaments remained intact. Lauge - Hansen (1950) reproduced this fracture in cadaver experiments by laterally rotating the supinated foot. The anterior tibiofibular ligament invariably ruptured before the fracture occurred, and bone flakes were detached from either the tibial or fibular insertions of the ligament. The same author (1952) drew attention to the presence of these lesions in patients, and presumed that the mechanism was identical. The experimental evidence for this initial stage in the production of this fracture is fairly strong, since avulsion of the anterior tubercle of the tibia had been previously recorded by Hönigschmied (1877), Le Roy (1887), Stimson (1892) and Quenu (1907). This fracture is referred to by French authors as the Low Dupuytren fracture, as opposed to Pott's fracture which is called the "Dupuytren - type" fracture. Diastasis with central dislocation of the talus has since been incorrectly labelled Dupuytren fracture by British authors, a lesion which Dupuytren himself observed only once in the 207 ankle fractures he treated. In his cadaver experiments Maisonneuve found that, if the inferior tibiofibular ligaments yield when lateral rotation force is applied, diastasis occurs first and an oblique spiral fracture appears consecutively in the middle or upper third of the fibula. Maisonneuve's name has been attached to the rare fracture of the upper third, which he produced experimentally but did not observe in his clinical practice.

Fractures of the Fibula below the Inferior Tibio-Fibular Ligaments

In his experiments Dupuytren found that a fracture of the distal end of the lateral malleolus occurred when the foot was forcibly adducted. Among his patients he noted that this fracture was frequently found with a fracture of the medial malleolus. This observation was confirmed experimentally by Bonnet (1845).

Bimalleolar Fractures

The term, bimalleolar fractures, was first used in a classification of ankle fractures by Boyer (1845).

Astley Cooper (1823) described the bimalleolar adduction fracture, which he termed a dislocation of the tibia outward, and he was the first to comment on the obliquity of the fracture line of the medial malleolus - a piece of the adjacent tibial diaphysis is sometimes included. Under "partial dislocation of the tibia forward," Cooper illustrated a specimen in which there is an intertubercular oblique fracture of the fibula, together with a posterior marginal fracture of the tibia. In abduction fractures (dislocation of the tibia inward) he not only appreciated the necessity for diastasis to occur in order to allow upward and outward dislocation of the talus, but also recorded the avulsion of a small fragment from the lateral surface of the lower end of the tibia, which often accompanies this dislocation.

Trimalleolar Fractures

The term, trimalleolar fracture, was introduced by Henderson (1932) to describe the presence of fracture of the posterior margin of the tibia in addition to fractures of both malleoli. Destot had suggested previously that the posterior margin projected sufficiently to be considered a posterior malleolus.

Until the advent of X-Rays it was customary to classify fractures according to the method of their production, namely, by abduction and adduction, since the part played by lateral rotation was not generally appreciated until the publication of Ashhurst and Bromer's paper in 1922. Radiological examinations, however, enabled fractures to be classified on a pathologico-anatomical basis according to the position and type of fracture line. Quenu (1912) produced an elaborate system on this basis. Recent anatomical classifications will be discussed later, after the development of the mechanistic classification has been traced further.

Classification of Ankle Fractures by Mechanism of Production

In 1910, Lane divided fractures produced by abduction of the talus into three degrees, and adduction fractures into two degrees, progressing in severity. According to Trethowan (1926) Lane's first degree abduction fracture was an oblique fracture of the lateral malleolus. The second degree included fracture of the medial malleolus or rupture

of the deltoid ligament. The Pott-Dupuytren fracture with diastasis was considered a subtype in which the fibula is fractured above the inferior tibiofibular joint, instead of below it as in the case of an oblique fracture. The third stage included posterior dislocation of the foot and posterior marginal fractures as well. Adduction fractures of the medial and lateral malleoli without displacement were included in the first degree, and with displacement in the second degree.

Ashhurst and Bromer (1922) classified oblique fractures of the fibula in a separate group as fractures by lateral rotation, in addition to fractures by abduction and adduction. They likewise graded the lesions into three degrees in each group, but included posterior marginal fractures as a complication of second degree fractures. The third degree consisted of supramalleolar fractures of the tibia and fibula, which do not involve the ankle joint and therefore cannot be regarded as lesions of greater severity. A fourth group consisted of compression fractures.

This method of classification and that of Lane have been developed further by Bonnin (1950), who stressed the importance of the presence or absence of diastasis, or, in the case of lateral rotation fractures, of damage to the deltoid ligament. If, on clinical grounds, there is the slightest suspicion that the fracture is associated with additional damage to ligaments, he recommended a meticulous routine of investigation prior to reduction, including bimalleolar views and radiographs with the foot in extreme plantar flexion. The three degrees of severity introduced by Lane and perpetuated by Ashhurst and Bromer form the basis of this classification, but trimalleolar fractures replace supramalleolar fractures in the third degree.

The methods of classifying ankle fractures discussed above are based on mechanistic principles derived in the main from experiments with cadavers during the latter part of the last century (Maisonneuve, 1840; Bonnet, 1845; Huguier, 1848; Tillaux, 1872; Hönigschmied, 1877). Recently, Lauge - Hansen (1950) conducted a new series of cadaver experiments to study the effect of forced manipulation of the foot in varying positions. Radiographs were taken at each stage of every experiment and compared with fractures found in clinical practice. He was able to classify 225 ankle fractures in adults according to the lesions found experimentally (Lauge - Hansen, 1952).

Three additional fractures could not be classified, and two of these were considered to be due to direct trauma. The titles, which Lauge - Hansen used to label each group of fractures, describe the mechanism found to produce the lesions experimentally. As his method of defining ankle movements differed slightly from that adopted here, his original titles are appended in brackets.

1. Supination-Adduction Fractures:- This type was produced by forced adduction of the hindfoot after the forefoot had been maximally supinated.
2. Supination-Lateral Rotation Fractures (Supination-Eversion Fractures):- When the leg had been fixed, the anterior part of the foot was maximally supinated, dorsiflexed, and then forcibly rotated laterally in this position.
3. Pronation-Abduction Fractures:- The foot was fixed in maximal pronation and the talus forcibly abducted by pressure at the knee.
4. Pronation-Lateral Rotation Fractures (Pronation-Eversion Fractures):- After the medial malleolus had been fractured by abduction of the pronated foot, the anterior part of the foot was forcibly rotated laterally.

Although not anatomically pure, these movements resembled conditions met with in normal life more closely than those in previous experiments. The more significant advances made in our knowledge of ankle injuries as a result of this work are as follows. Rupture of the anterior inferior tibiofibular ligament was found to occur in a much greater proportion of injuries of the lateral rotation type than previous surveys suggested. This was apparent whether the foot was initially supinated or pronated before the injury occurred. With the foot supinated, this appeared to be the initial lesion in a majority of cases and occurred even before the characteristic oblique fracture. Secondly, on lateral rotation of the supinated foot, fracture of the posterior margin of the fibula always occurred before fracture of the medial malleolus or rupture of the deltoid ligament, which is at complete variance with views previously held. Finally, the Pott-Dupuytren fracture has been produced experimentally by lateral rotation violence of the pronated foot.

More recently, Kleiger (1956) acknowledged the observations of Lauge - Hansen, but preferred to retain the classification of ankle injuries by lateral rotation, abduction, adduction, and compression violence. He stressed the distinction between tibiofibular diastasis and lateral ankle instability. He defined lateral ankle instability as excessive lateral displacement of the talus, with widening of the mortise and of the space between the talus and the medial malleolus. This may not be apparent until radiographs are taken under lateral rotation stress. The fractured lateral malleolus may be displaced laterally together with the talus, but, as long as the interosseous and inferior tibiofibular ligaments remain intact, the fibular shaft is held within the tibial groove. Thus, it is only when the fibular shaft is displaced laterally from its groove, that diastasis is said to occur. Lateral instability may take place in the absence of diastasis, if the fibula is fractured below the level of the inferior tibiofibular ligaments, or if the anterior inferior tibiofibular and interosseous ligaments rupture, allowing the fibula to rotate laterally in its groove without leaving it. He ascribed lateral ligament instability to tears of the medial portion of the capsule and anterior talotibial fibres of the deltoid ligament in lateral rotation injuries. Lauge-Hansen had shown previously that rupture of the anterior inferior tibiofibular ligaments usually occurred during the first stage of this injury and would allow lateral displacement of the talus and fibula for two to three mm. without injury to the medial aspect of the joint. Owing to the elasticity of the intact tibiofibular ligaments, the displacement disappeared as soon as lateral rotation was corrected. Lauge-Hansen regarded injury to the medial ligament as the final stage of a lateral rotation injury.

It is now clear that classification of ankle injuries according to mode of injury is no longer satisfactory. Not only do there appear to be an increasing number of possible mechanisms responsible, but general agreement has not been reached as to the progressive stages of existing mechanisms. In an attempt to simplify matters, Watson-Jones, Wiles and Adams have recently introduced a new classification which is partly anatomical and partly mechanistic (Watson-Jones, 1955), as follows:-

1. Avulsion of the ligaments of the ankle from momentary dislocation (sometimes associated with

avulsion of fragments of bone).

2. Avulsion of the ligaments of the ankle joint with malleolar fractures (avulsion fractures of medial and lateral malleoli and attachments of inferior tibiofibular ligament).
3. Malleolar fractures without displacement (isolated fractures of lateral and medial malleoli, and anterior and posterior margins of the lower end of the tibia).
4. Fractures of the ankle joint with lateral or posterolateral dislocation (including spiral fractures of the lateral malleolus with avulsion of the medial ligament and lateral displacement, Pott-Dupuytren and Maisonneuve types of fracture-dislocation, as well as those involving the posterior margin of the tibia).
5. Fractures of the ankle joint with medial or posteromedial dislocation (bimalleolar adduction fractures).
6. Fractures of the ankle with forward dislocation (anterior marginal fractures).

Classification of Ankle Fractures by Anatomical Site

The foregoing classification of injuries, which is partly anatomical and partly mechanistic, may become recognised generally. However, at the time when the material for this thesis was being collected, a purely anatomical classification based on X-Ray findings was almost universal. Radiographs were not available when the material for Series B (1946 - 51) was compiled from the case notes of my predecessors at Chessington. The anatomical site of the fractures had been recorded in every case, although the exact level of the lesion was not always clearly stated. The mechanism of fracture was infrequently recorded. Consequently, descriptions such as "Fracture lateral malleolus" might refer to oblique fractures indicating external rotation violence, or transverse fractures due to abduction or adduction violence. However, additional complications such as diastasis were satisfactorily noted. Except in a few of the early cases, radiographs

were available when the material for my own Series A (1952/3) was analysed. From the radiographs a mechanistic classification could have been adopted for this series, but a comparison could not be made with the earlier group (1946/51).

I have therefore adopted an anatomical classification in which greater consideration is given to mechanistic principles than in previous classifications of this type, (Tanton, 1916; Sear, 1917; Svend Hansen, 1919; Henderson, 1932). Henderson grouped fractures of the ankle as follows:-

Group 1. Isolated malleolar fractures

1. Fracture of medial malleolus.
2. Fracture of lateral malleolus.
3. Fracture of posterior malleolus.
4. Fracture of anterior margin of the tibial articular surface.

Group 2. Bimalleolar fractures

1. Fracture of medial and lateral malleoli without displacement of talus.
2. Fracture of medial and lateral malleoli with displacement of talus (Pott's fracture).

Group 3. Trimalleolar fractures

Fractures of all three malleoli with displacement of talus laterally or posteriorly.

I have aimed at grouping fractures of similar severity together, separating simple fractures from those in which diastasis or lateral instability has occurred. The nature of the deforming force can be determined from the site and type of fracture, according to the mechanisms outlined by Bonnin (1950) and Lauge-Hansen (1950). (See Table I)

Although this classification appears to be a catalogue of ankle fractures, many of the fractures listed are rare, and others can be grouped under one heading where the duration of immobilization and rehabilitation is similar. In addition, isolated fractures of the lateral malleolus

must be separated from those of the medial malleolus, which show a greater tendency to delayed or non-union. Fractures of the fibula have been separated into three main groups in a manner similar to the anatomicopathological classification of Ashhurst and Bromer (1922), which is not so well known as their mechanistic grouping. Details are as follows:-

- (1) Basal fractures below the level of the inferior tibiofibular ligaments with which diastasis does not occur.
- (2) The common "Mixed Oblique" fractures of the lower end of the fibula, in which the fracture line commences anteriorly on the surface of the fibula at the level of the weightbearing articular surface of the tibia (plafond). It extends upwards and posteriorly between the tibiofibular ligaments attached to the anterior and posterior tubercles of the tibia and fibula, hence the description Intertubercular. In the majority of cases the fracture is not displaced and unites satisfactorily if lateral rotation is guarded against for a few weeks. A few cases, however, show a tendency for the lateral malleolus to displace laterally, due to rupture of the anterior inferior tibiofibular ligament or deltoid ligament. These fractures have been grouped separately.
- (3) Fractures above the level of the inferior tibiofibular ligaments are invariably associated with at least partial diastasis, unless due to direct violence. The title Supratubercular has been introduced to emphasise this association, irrespective of whether the fracture was produced by abduction or lateral rotation violence. With these fractures, delayed weightbearing after accurate reduction is essential in order to avoid a painful unstable ankle. The only exception to this rule is that a transverse fracture of the fibula may occur about an inch above the level of the upper articular surface of the talus, together with a vertical fracture of the medial malleolus due to adduction violence. This appears to be due to an unusual avulsion force, and diastasis does not occur.

The two types of fracture of the medial malleolus, transverse and vertical, and the three levels at which the

fibular fractures occur are included in the Bimalleolar and Trimalleolar groups. With this system, increasing anatomical damage closely parallels the grades of severity deduced from mechanistic experiments.

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METHOD OF SURVEY

1. Selection of Material

Fractures of the shaft of the tibia and fibula, and fractures of these bones involving the ankle joint, have been selected for study together, because they present similar problems in rehabilitation and have been treated in R.A.F. Rehabilitation Units in the same remedial classes. As patients with fractures of the tibial condyles are normally rehabilitated with patients with other knee injuries in the Quadriceps and Knee classes, these fractures have been excluded from the survey. A small number of patients who sustained multiple fractures involving other bones of the legs (although of interest in showing what can be done to improve function after severe trauma by full-time treatment) present individual problems, which defy comparison in a survey of this nature, and this group has also been excluded.

Two groups of patients have been studied. Series A contains 97 patients with fractures of the shaft of the tibia and fibula, and 61 patients with fractures involving the ankle joint, who were personally treated by me at Chessington between October 1951 and December 1953. Apart from the groups mentioned in the preceding paragraph, all patients with these types of fracture, who were admitted during this period, were included in the survey. Series B contains 111 patients with shaft fractures, and 82 patients with ankle fractures, admitted to the unit between October 1946 (when the present regime of class exercises was commenced) and September 1951. These patients were in the care of several successive medical officers, and the object in compiling a record of the results of treatment in this group was to estimate to what extent my personal interest and supervision were influencing a traditional rehabilitation programme already in force. Unfortunately, the case notes from which these records were compiled were frequently incomplete. This appears to be a not uncommon finding in retrospective surveys. The original hospital notes had been returned to the numerous hospitals from which they originated, and only notes compiled by medical officers at the unit were readily accessible. 45 per cent. of the case notes had to be discarded as the basic information required - the duration of plaster treatment

and subsequent mobilization - was not recorded, leaving only 55 per cent. of the fractures admitted to the unit during this period available for survey.

2. Composition of the Proformas.

During the first six months of the study of my personal series of patients (Series A), weekly observations were recorded of characteristic gait patterns, ability to run, ability to stand on the toes, and ankle and knee joint ranges. From the experience gained from the 39 patients seen during this period, grading of the various stages of the process of rehabilitation was found to be practical, so that a series of standard observations could be recorded on a proforma.

For the remaining 119 patients in Series A, the proforma was used from the time of removal of the plaster, or from arrival at the unit, if this was after removal of the plaster. The proforma was arranged to record a separate weekly assessment for each patient, with attention to the following particulars:-

- (1) the nature, site and character of any pain experienced;
- (2) the degree and site of any oedema present or of evening swelling of the limb noticed by the patient;
- (3) the character of gait on walking without the use of sticks;
- (4) an assessment of the patient's ability to run;
- (5) an assessment of the patient's ability to stand on the toes of his injured leg, with or without support, and to hop;
- (6) range of active movement in the knee joint;
- (7) range of active movement at the ankle joint;
- (8) range of active supination and pronation of the foot;
- (9) range of passive movement at the subtaloid joint;
- (10) an assessment of power of the quadriceps, ankle dorsiflexor, supinator and pronator muscle groups;
- (11) details of the treatment programme.

Oedema was recorded as ++, if the limb was grossly swollen and deep pitting was present after pressure with the finger-tips. This was rarely observed, and the sign + was used to describe the average swollen limb, in which pitting was obtained without difficulty. A trace of oedema was considered to be present if, although the limb was not obviously swollen, slight pitting was obtained with careful palpation of the subcutaneous surface of the tibia. "Oedema ex." was used to describe the state in which there was no evidence of oedema on examination, although the patient described the limb as becoming swollen after exercise or at the end of the day. A "nil" recording was made only when the patient no longer complained of swelling at any time.

Progress in walking was graded in five stages according to the amount of limp present. At the end of the first stage the patient was taking one-half his normal stride with his uninjured leg without sticks. In this state he was just able to bring his good leg level with his injured leg on walking, progress being initiated with the injured leg. As the stride of the sound limb increased, a second stage was recorded when the patient was taking three-quarters of his normal stride with this leg. Forward progress was now being made with the sound limb but the paces were obviously still uneven. In the third stage the steps were now equal or almost so, but there was still a well-marked limp since the patient was unable to push himself off on to his toes with his injured limb. The fourth stage was recorded when the strides were equal, only a minimal limp being apparent on careful observation. The patient passed into the fifth stage when normal gait was attained.

Progress in learning to run was also recorded in five stages:-

First stage: two separate mechanisms were noted in different patients. In one group patients started to run by attempting to stride out, the steps becoming very uneven, and the gait being best described as a flat-footed hobble. In the second group patients tried to get on their toes first and consequently moved slowly forward taking short steps (trot).

Second stage: in both groups progress was made until the strides were almost even. Loss of spring resulted in inability to lift the heel off the ground, so that a definite flat-footed pattern persisted.

Third stage: the strides were now even and approached normal in length, but a slight limp was still present.

Fourth stage: the limp had now disappeared under examination conditions, but it appeared towards the end of the test (second time across the examination room) and on continuous running.

Fifth stage: normal running except over long distances (several miles).

The patient's ability to stand on his toes was recorded in six stages:-

First stage: standing on toes of both feet with most of weight on the sound leg.

Second stage: standing on toes of both feet with weight evenly distributed.

Third stage: standing on toes of fractured leg alone with considerable support, i.e. the support of both examiner's hands was required when the patient stretched his hands out in front of him.

Fourth stage: as stage 3, but no more support required than supplied by two of the examiner's fingers.

Fifth stage: just able to stand on toes of fractured leg without support.

Sixth stage: standing readily on toes of fractured leg without support.

Hopping was recorded in 5 stages. Records of this test were limited, as it was not added until a fairly late stage of the survey.

First stage: hopping flat-footed on injured leg once. The heel barely left the ground.

Second stage: hopping flat-footed without difficulty.

Third stage: hopping on toes once or twice only.

Fourth stage: hopping on toes without difficulty, but lack of spring was still present when compared with the sound leg.

Fifth stage: normal.

For the remaining observations the patient was seated on a couch with his knees slightly flexed.

The range of movement of the knee joint was measured by means of a protractor arthrometer. The longitudinal axis of the lower three inches of the thigh, and of the upper three inches of the lower leg, were visually assessed, when the shafts of the arthrometer were held against the centre of the lateral aspect of the limb. The angle between the two axes was recorded from the protractor scale.

The range of movement at the ankle joint was difficult to estimate clinically, as it is not easy to locate satisfactory landmarks. More useful information could be gained from studying the movement of the foot as a whole in relation to the longitudinal axis of the leg. The centre of the lower three inches of the leg viewed, from the lateral aspect was taken as the baseline for the protractor scale. From a functional aspect, it is important to know the angle between the weight bearing surface of the foot and the longitudinal axis of the leg when the foot is dorsiflexed. If this angle is increased beyond 90 degrees, walking becomes difficult. To measure this angle the patient dorsiflexed his foot to the full extent. The second arm of the protractor scale was placed parallel to the line between the weightbearing surface of the foot under the 5th metatarsal-phalangeal joint and the heel. The range of plantar flexion of the foot is of value in estimating whether any difficulty, which the patient experiences on rising on to his toes, is due to joint stiffness rather than weakness of the calf muscles. This could be measured by the angle between the axis of the lower end of the leg and the line joining the transverse axis of plantar flexion through the body of the talus and the 5th metatarsal-phalangeal joint. For practical purposes the latter is almost identical with the longitudinal axis of the 5th metatarsal bone, which, even in a cavoid foot, can be measured with greater accuracy. Salter (1955), in an extensive review of methods of measurement of joint and muscle function, considered that the use of the simple protractor type of arthrometer was the most satisfactory method of measuring joint function. Inaccuracies with this instrument are mainly due to faulty positioning. Using the landmarks described above, identical readings were normally obtained on repetition. An error amounting to 2 degrees was rare.

The terms, supination and pronation of the foot, have been defined above. The extreme active range of these movements was compared with those of the normal foot. A

mental estimation of the degree of rotation of the forefoot, when fully adducted or abducted, was made and recorded as $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ of normal, nearly normal (90 per cent.), or normal. It was later found that, in a number of patients, compensatory increase in the range of movement in the midtarsal and tarso-metatarsal joints allowed rotation to be assessed as almost normal, even though subtaloid movement was virtually nil. An estimate of the passive "subtaloid rock" was therefore added to the survey. The range of tibial flexion and fibular flexion of the calcaneum at this joint was recorded on the same scale as rotation of the forefoot.

The selection of a method of measuring the muscle power of ankle and foot movements proved difficult. One of my colleagues was successfully using the vertical resistance of a spring balance to record quadriceps power in raising the straight leg off the examination couch (Millard, 1952). Extension of this method to record ankle and foot power was not satisfactory, owing to difficulty in ensuring that the position of the foot and the consequent pull were identical on each examination. A method of recording resistance offered by the muscles in isometric contraction appeared to be more practical. A Newman myometer, which uses a hydraulic pressure convertor, was considered for the purpose. This instrument can be used to test most muscle groups (Newman, 1949), but enquiries indicated that it was not available in this country. However, manual testing was found to give consistent results. Excluding those cases in which peripheral nerve lesions complicated the fracture, all muscle groups were capable of acting against gravity and resistance. Muscle power was therefore graded according to the patient's ability to hold the foot or leg at the extreme range of each movement.

Grade 1: position held only against very light resistance.

Grade 2: position held against moderate resistance - approximately half the resistance produced in the normal limb. Position readily lost if maximum manual resistance applied.

Grade 3: position held against considerable resistance, but position gradually lost if maximum resistance applied.

Grade 4: position held against maximal manual resistance for up to 5 seconds, and then gradually lost.

Grade 5: normal. Position held against maximal manual resistance and sustained for over 5 seconds.

The sound limb was always tested first. In most cases the patient could maintain the position of the normal limb against the full power of the examiner's hand. In a few cases in which movements were not sustained in the normal limb, resistance was reduced until could be graded 5, and the injured limb tested with the reduced resistance. The assessment was therefore a comparative one in terms of function of the normal limb.

There was also a space on the weekly chart to record the presence of any foot deformities, range of movement at metatarsal-phalangeal joints, power of intrinsic muscles, and the presence of knee or ankle effusions. The amount of shortening of the limb (if present) was recorded on removal of plaster or on arrival at the unit. Measurements were taken from the inferior margin of the anterior superior iliac spine to the tip of the medial malleolus. Muscle bulk was measured at the same time and again prior to discharge. The circumference of both thighs was measured with minimum tension at a point five inches above the patella. The maximum circumference of the calf muscles was recorded in the same way.

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RESULTS OF ANALYSIS OF THE PROFORMAS

The proformas were analysed in three sections for both the diaphyseal and malleolar fractures of the tibia and fibula. The first section deals with the factors which might influence both the period of immobilization in plaster and the subsequent restoration of function. The second section shows the results of investigating the rate of recovery of muscle power and joint movement after immobilization. The third section is concerned with the study of additional measures, such as physiotherapy, occupational therapy and hydrotherapy, which were already in use at the rehabilitation units during the recovery period. It was felt that these would form a basis for the selection of treatments which were most likely to influence the rate of recovery in future investigations.

The term, recovery time, has been used to describe the number of days from the removal of the plaster until the patient was fit for discharge from the centre.

THE IMMOBILIZATION PERIOD

The following factors were investigated: (a) the nature of the fracture, which included the anatomical site with associated pathology; (b) the age of the patient; (c) the method of reduction and fixation of the fracture; (d) the observer variation in the assessment of time for removal of plaster; and (e) the influence of treatment at the rehabilitation centre while the fracture was in plaster.

Diaphyseal Fractures of the Tibia and Fibula

(a) The Nature of the Fracture

It has previously been the custom, in assessing the effect of the site of the fracture on the patient's progress, to divide the diaphysis into upper, middle and lower thirds. Some authors consider separately the level of the junction of the middle and lower thirds, in view of the frequency with which this region is involved. Spiral fractures of the lower third of the tibia and upper third of the fibula should probably form another group.

The mean duration of immobilization in plaster and the subsequent period of recovery before the patient was fit for

discharge is presented in Table II. The fractures have been divided into two main groups, simple and compound: these groups have been further subdivided into Series A (personal group, 1952/3) and Series B (control group, 1946/51). It will be seen that, when both the tibia and fibula are fractured, the mean duration of immobilization is about one month longer than when the tibia alone is fractured, as long as the fracture is simple. For compound fractures the numbers are too small to show any significant trend, but the results of both groups of fracture can be presented together without affecting the means. For similar reasons the fractures requiring a bone graft on account of non-union can be grouped together. For the subsequent analyses fractures of the tibia and fibula have therefore been divided into four groups, namely, simple fractures of the tibia and of the tibia and fibula, compound fractures, and fractures requiring a bone graft.

When the site of fracture is considered, there is little difference between the various groups, with the exception of the fractures involving the lower third of the tibia and fibula in Series A, where the longer duration of immobilization is very likely to be explained by the small size of the sample. A number of the mean figures for the recovery time have been included in brackets; this indicates that an extraneous factor has occurred during this period, and one or more patients have been excluded from this sample although they have been included in the figures for immobilization in plaster. For fractures at the junction of the middle and lower thirds of the tibia in Series A, one patient was involved in a road accident before rehabilitation was completed. In the unspecified fractures of the tibia and fibula in Series B, one patient developed a posterior tibial nerve lesion as a result of his fracture, which necessitated treatment for 233 days. A second patient was invalided on the 22nd day due to marked pes valgus, resulting from deformity at the fracture site; the rehabilitation could not be considered complete at this stage. The patient with the compound fracture involving the lower third of the tibia and fibula in Series A was returned to hospital for invaliding on the 35th day, on account of an associated paralysis of the 5th and 6th cervical nerves before the rehabilitation of his leg had been completed. The patient with the compound spiral fracture in the same series was returned to hospital for exploration of a sinus which had caused persistent trouble during the plaster period and broke down again at the rehabilitation

centre. The patient with the unspecified compound fracture of the tibia and fibula in Series B was invalided on the 202nd day on account of a posterior tibial nerve palsy.

The frequency distribution for the duration of immobilization in plaster for the different types of fracture is set out in Table III. It will be seen that, for fractures of the tibia alone, the group which occurs most frequently is that for fractures immobilized for between 2 and 3 months (57 to 84 days). The frequency distribution falls in the subsequent groups and is low after the fourth month. For fractures of both tibia and fibula the maximum incidence is in the third to fourth month (85 to 112 days); and it will be observed that this also applies to compound fractures. The next highest incidence for fractures of the tibia and fibula is in the periods fourth to fifth month (113 to 140 days) and second to third month (57 to 84 days): the figures are almost identical. After the fifth month, the groups are relatively small, although three fractures were immobilized for over 9 months. There is no difference in the frequency distribution at the different fracture sites. If, as is sometimes stated, fractures involving the lower end of the diaphysis of the tibia take longer to unite, there would have been a shift to the right of the frequency distribution of these groups in all three sections of the table.

The rate of union of fractures is analysed in Table IV. For fractures of the tibia alone, 60% of the fractures had united sufficiently to allow removal of the plaster by the 12th week (84th day), 83% by the 16th week, and 92% by the 20th week - for practical purposes, approximately 60%, 80% and 90% respectively. For simple fractures of the tibia and fibula, the approximate percentages are 20%, 50% and 70%; and for compound fractures 10%, 33% and 50%. For convenience the number of fractures which showed delayed union at the three stages is shown in the lower part of the table. It will be seen that the percentage of patients who required a bonegraft owing to initial non-union increased very considerably when the fractures were compound.

Analysis of the Accidents resulting in Fractures. The various methods by which the patients in Series A sustained their fractures are set out in Table V. In the majority of cases, motor cycle accidents and soccer injuries were responsible. The relatively high incidence of compound fractures in motor cycle accidents should be noted, in contrast to the very

high incidence of simple fractures in soccer injuries. There were insufficient data available in the case records of the Series B patients to allow a similar analysis to be made. However, similar trends could be seen. Practically all the soccer injuries were sustained in organised games, whereas all except two of the motor cycle accidents occurred while the patient was off duty. Only one of the 208 patients was injured in an aircraft crash (Series B) since few patients referred to this rehabilitation unit were concerned with the flying or servicing of aircraft in their normal duties.

(b) The Age of the Patient

The effect of age on the duration of immobilization in plaster is shown in Table VI. Altogether, 208 patients could be conveniently allocated almost equally to three age groups, viz. 16 - 19, 20 - 24 and 25 - 47 years. With the exception of simple fractures of the tibia, there was a slight tendency for the duration of immobilization to increase in the two older age groups; it is impossible to make a more definite statement as the figures in the later groups are too small for statistical analysis. Although it does not appear in the Table, the 25 - 47 age group was subdivided into 25 - 32 and 33 - 47 age groups. The 25 - 32 figures were very similar to those in the previous age group (20 - 24), so that the increased period of immobilization was essentially in the 33 - 47 age group.

In Tables II to V a close similarity will be observed in many groups between the mean duration of immobilization of fractures in Series A and Series B. This would suggest that the immobilization stage in the treatment of fractures has remained constant during the two periods.

(c) The Method of Reduction and Fixation of Fractures

After the injury had been sustained, the initial treatment of a fracture was carried out in no less than 36 different civilian hospitals and 21 different Service hospitals. In Series B treatment was initiated in 24 civilian hospitals and 21 Service hospitals, but in 45 patients the place at which treatment had been begun was not recorded. Thus, a wide cross section of orthopedic surgical practice in this country was obtained.

Sir Reginald Watson-Jones has suggested that the reduction and fixation of the fracture should be satisfactorily completed by the end of the first week, so that there should be as little interference as possible with the more vital stage in the process of union during the subsequent weeks. These observations were considered in the analysis of methods of reduction and fixation of fractures in this survey as shown in Table VII. The patients have been divided into three groups according to whether (1) reduction of the fractures had been completed during the first week, (2) the fracture had been disturbed by further manipulation, wedging or open reduction after the first week, or (3) skeletal traction had been employed.

In all, 45 patients in Series A were treated in civilian hospitals and 52 in Service hospitals; in 16 of the civilian-treated patients and 21 of the Service-treated patients manipulation of the fracture or operation had been necessary after the seventh day. Skeletal traction has been condemned in recent years as a method of maintaining reduction. This method of treatment had been used for 6 of the patients in civilian hospitals and for 12 patients in Service hospitals; 5 of these patients had been treated in one Naval hospital. Unfortunately the case records used for the Series B fractures omitted to mention the method employed in the initial treatment of the fractures in more than half the number of patients. The limited records are, however, of value in substantiating trends observed in the Series A groups, which are necessarily of small size.

The most significant trend shown in Table VII is seen in the 17 patients treated by skeletal traction. Both the time in plaster and recovery time are prolonged in five of the six groups, but reference to Table VIII shows that in Series A the group treated by skeletal traction does not compare unfavourably with the group treated by open reduction. In three patients skeletal traction was discontinued within the first month, and these fractures had all united by the end of the 12th week, but in the remaining 14 patients half the fractures had not united within six months. This suggests that continuation of skeletal traction into the second month may delay union and prolong recovery time.

Owing to the small size of the samples, no conclusion can be drawn regarding the effect of disturbing the fracture after the first week, in connection with the groups containing (a) fractures of the tibia alone, or (b) compound fractures.

However, the simple fractures of the tibia and fibula can be divided into two groups containing 39 and 33 patients (Table VII). The overall figures for both Series A and Series B indicate that fractures disturbed after the first week take from 2 to 4 weeks longer to unite. More detailed examination of the individual methods of treatment reveals a difference between the composition of the groups of patients in Series A and Series B treated in plaster only. In fractures reduced during the first week, the figure of 111 days for the mean duration of immobilization in Series B is probably abnormally high. These fractures were all reduced under a general anaesthetic, indicating initial violence of greater severity than occurred in the Series A group (who were 97 days in plaster), in which only half the fractures required manipulation under an anaesthetic to effect reduction. In 4 undisplaced fractures the mean duration in plaster was only 65 days. The effects of further manipulation or wedging of a fracture after the first week cannot be adequately compared as the samples are small. The majority of fractures in Series A were wedged (140 days in plaster), whereas most fractures in Series B were manipulated (111 days in plaster). The duration of immobilization in plaster following immediate screwing of oblique and spiral fractures compared favourably with fractures treated by closed reduction. The mean plaster periods were: fractures of tibia 53 days, tibia and fibula 87 days (Series A) and 108 days (Series B), and compound fractures 86 days. On the other hand plated fractures required more prolonged immobilization partly on account of comminution and partly due to delay in operation, which was performed in the majority of cases during the fourth week. Delay in screwing fractures may also increase the time in plaster. The three main methods of effecting and maintaining reduction of fractures have been compared in Table VIII. The figures for open reduction include those fractures treated by immediate screwing, which, as we have seen, behave in a manner similar to fractures treated by closed reduction, and could well be included in the latter group without increasing the mean. This would result in a corresponding increase in plaster and recovery times for the remaining fractures treated by open reduction.

Fractures treated by bonegrafting for non-union present individual problems, which cannot be analysed by the group method. The plaster and recovery times, which are shown in Table II, depend upon the delay which occurs before grafting is contemplated. In Series A, 4 out of the 5 fractures

were grafted between 110 and 194 days after the initial accident, whereas in Series B only two fractures were operated on during this period, and the remainder at approximately 300 days after injury. Recovery time was also prolonged in 2 patients in Series A by treatment in a caliper (following immobilization in plaster for 227 and 268 days respectively). Non-union had been attributed to a plate forcing the fragments apart in one patient, rotation of the fracture round a screw in another, and skeletal traction in a third. In the remainder no definite explanation was found for failure of the fractures to unite. The method of operation adopted for the Series B patients had been a sliding graft. In the later Series A, the usual procedure was to trim the bone ends and to pack the fracture site with bone chips. In one patient fixation had been secured by an Eggers plate and in two others by Küntscher nails.

It will be seen from Table II that one patient in Series A, who had sustained a compound fracture of both tibia and fibula did not have his plaster removed finally until 560 days after his initial accident. His case history is recorded in detail as it illustrates the use of treatment at a rehabilitation centre when union is delayed for long periods. In his case a sliding bone graft operation had been performed for non-union 118 days after the initial injury. A walking caliper was fitted on the 192nd day, and he arrived at the rehabilitation centre a month later with a grossly oedematous leg. He remained under the supervision of the civilian orthopaedic surgeon who reviewed him periodically. By the 328th day the oedema had almost disappeared, but union was unsound, being of the short fibrous type; knee flexion was only 50° and the ankle was held in 10° equinus. No further operation was contemplated, and he was discharged after being advised to discard the caliper gradually. However, one of the visiting R.A.F. orthopaedic surgeons decided to consider further operation after the knee and ankle joints had been mobilized. The caliper was discarded, resulting in considerable angulation at the tibial fracture site. After 4 months 115° of knee flexion had been obtained, and the ankle could be dorsiflexed to 90°. Anterior wedge osteotomy was performed on the 477th day, and, after removal of sclerotic bone, the fracture site was packed with bone chips. Osteotomy of the fibula was undertaken at the same time. He remained in plaster until the 560th day

and arrived back at the rehabilitation centre 2 days later with 65° of knee movement; 120° was regained within three weeks. On discharge after 14 weeks treatment, he was free of symptoms, including swelling of the leg. There was minimal varus deformity of the leg and half an inch shortening. He was walking without a limp and could run for some time with only a slight tendency to limp. Knee movement was almost full (133°) and the range of active movement of the ankle and foot was 90° to 130° . He was fit for his Service job as an engine fitter, but, since he was due for demobilization shortly after discharge from the centre, a similar job had been found for him in an aircraft factory through the resettlement clinic while he was undergoing treatment. This history demonstrates the necessity for close liaison between the orthopaedic surgeons and the treatment staff of the rehabilitation centre, so that the patient's ultimate functional requirements not only for Service duties but also for civilian life may be discussed, and appropriate treatment instigated.

Since the initial treatment was carried out at a large number of different hospitals, some variation was to be expected in the standard of acceptance of reduction and in the time for removal of the plaster. The amount of angulation at the fracture site was measured from the final radiographs of the fractures in Series A. Over 10° of lateral angulation was recorded in 2 patients, who had sustained simple fractures. In 14 patients union with 5° to 9° of medial or lateral angulation was present (6 compound, 8 simple fractures). Over 10° of anterior or posterior angulation remained in 5 patients (3 compound, 2 simple fractures), and 5° to 9° had been accepted in a further 7 patients. Of the 7 patients, who were left with over 10° of angulation of their leg, only one patient had been treated at an R.A.F. orthopaedic centre. The first attempt at reduction had been complicated by fat embolism, and 12° of anterior angulation had been accepted. This did not produce any disability during the recovery period, and he was running and jumping within seven weeks of removal of his plaster. As a group, the 24 patients, in whom over 5° of angulation of the fracture had been allowed to remain, showed a high incidence of delayed union. Eight fractures (33%) had not united after six months in plaster.

Lateral displacement of 0.4 to 0.5 inches (1.0 to 1.25 cm.)

was present in 7 fractures, and as much as one inch remained in an infected compound fracture. Again, over six months' delay in union was observed in 3 patients (37%). In several patients, the initial reduction was corrected after the patient had been transferred to the care of an R.A.F. orthopaedic centre. One fracture had been left with practically no contact between the bone ends. Open reduction was performed with difficulty on the 28th day and fixation secured with a Burns plate. The plaster and recovery times were 124 days and 85 days respectively. In the majority of cases permanent shortening was not more than $\frac{1}{4}$ inch (0.6 cm.); $\frac{3}{8}$ inch (0.9 cm.) shortening was recorded in 4 patients, $\frac{1}{2}$ inch (1.25 cm.) in 4, $\frac{3}{4}$ inch (1.9 cm.) in 3, and one inch (2.5 cm.) in one. As implied in the earlier stages of this analysis, it was customary to maintain immobilization in plaster until clinical union had occurred, or, in a few cases, until the stage had been reached when a walking caliper was a more satisfactory alternative. In Series B a few fractures were protected by a plaster back splint during the early part of the recovery stage, but this method was not used in my own series, to which the figures in this paragraph relate. The non-weightbearing period in plaster varied considerably according to the rate of union of the fracture and the experience of the medical officer supervising treatment. The average period before allowing weightbearing was approximately 36 to 40 days for fractures of the tibia alone, and for fractures of the tibia and fibula which were reduced in the first week. For fractures of both bones, in which reduction was delayed or in which skeletal traction was employed, the period was 58 to 66 days; for compound fractures, this stage varied from 24 to 165 days. Eleven patients, with undisplaced fractures of either the tibia alone or the tibia and fibula, were allowed to weightbear within the first fortnight.

(d) The Observer Variation in assessment of time for removal of plaster

In my own patients clinical union was estimated in the normal manner, and the patients were allowed out of plaster as soon as the fracture was no longer tender and resisted springing without pain. Radiological consolidation was never complete at this stage, but, as long as the fracture appeared to be stable and a continuous bridge of callus of sufficient width and density was present across the fracture site, patients did not experience any difficulty in coping with the subsequent rehabilitation programme. The fracture line

was frequently visible when the patient reached the late stage, during which the class programme included running over rough ground and jumping. When these activities were carried out before radiological consolidation have been completed, repetition of the X-Ray films did not reveal any disturbance in the alignment of the fractures. In fact, the radiological appearances were sometimes an inaccurate guide to the amount of violence a fracture would stand.

In one patient the tibia had been plated following fracture of the lower quarter of the tibia and fibula. A walking caliper was fitted after 108 days, because the X-Ray films showed very little callus formation. Some 18 days later, the patient stepped off a pavement with his good leg and overbalanced. The caliper snapped, as well as the heads of two screws holding the plate to the tibia, but the fracture itself was not disturbed.

Pain at the fracture site after the plaster has been removed may result in slow progress for several months as the patient continues to guard his leg. Occasionally the pain is of soft tissue origin, but, unless the patient can confidently be shown a soundly consolidated fracture on the X-Ray plate, a further period in plaster results in more rapid ultimate progress. A walking caliper is not the complete answer to this problem.

The shortest period of plaster immobilization in either series was 44 days for a fractured tibia, but the recovery stage lasted as long as 72 days. A displaced transverse fracture of the midshaft of the tibia (Series B) was taken out of plaster on the 48th day and non-weight-bearing exercises were commenced, but the fracture site became tender and painful five weeks later, and the X-Ray films showed that mushrooming of the callus had occurred. A further period in plaster was necessary between the 91st and 122nd day, after which the patient required another 6 weeks rehabilitation. The shortest total treatment time for fractures of the tibia alone was 51 days in plaster, after which full mobility was regained in 16 days (Series B). For fractures of the tibia and fibula the corresponding period was 55 days in plaster, followed by full recovery in 36 days (Series A). Shorter recovery times were recorded, however, following longer periods in plaster. These figures probably represent the shortest periods of plaster immobilization which can be allowed without unduly prolonging the recovery time.

An unorthodox method had been used to treat a compound fracture of the midshaft of the tibia and fibula, which was plated on the 19th day. A backsplint was applied and exercises for the knee and ankle were commenced in bed on the 22nd day. After 7 weeks, the leg was encased in a plaster cylinder from the knee to the ankle and weightbearing commenced. The patient was then evacuated by air to this country and changed surgeons! A walking plaster was applied from above the knee to the toes after 11 weeks, and was removed after 107 days (15 weeks). He arrived at the rehabilitation centre 3 days later and was walking without a limp in 10 days. He was fit for demobilization and proceeded to a heavy civilian job as a steel erector at the end of a month.

In contrast, a small number of patients were seen, in whom complete radiological consolidation of the fracture had occurred before the plaster had been removed. Fractures were seen which had been overimmobilized by as much as 3 months according to the standards which I had adopted. A further example illustrates this opposite extreme in current orthopaedic practice.

The patient was admitted to a remote country hospital with an oblique fracture of the midshaft of the tibia and fibula, which was reduced under a general anaesthetic, but half an inch of medial displacement and $\frac{3}{4}$ of an inch of overriding of the lower fragment persisted. He remained in bed until the plaster was removed after 14 weeks, practising toe and straightleg-raising exercises for ten minutes during each hour. He was then allowed up in a walking caliper and arrived at the rehabilitation centre 18 days later. Union was clinically sound, but radiological consolidation had progressed to the stage in which the laterclass regime of running and jumping would normally be permitted. The caliper was therefore removed.

(e) The Influence of Treatment at the Rehabilitation Centre while the Limb is in Plaster

In the preceding paragraphs a quantitative analysis has been presented of the material in this survey; an examination has also been made of the influence of the judgment of individual medical officers as to how long immobilization should be continued. In contrast, the present

section deals with what is in effect an experiment to determine the results of one form of physical treatment on the rate of recovery after fractures of the leg. The effect of treating patients who arrive at the centre in plaster has been compared with the progress made by patients who commence the regime after the plaster has been removed. The selection of patients for each group appears to be purely at random. Some surgeons wish to supervise their patients personally until the fracture has united satisfactorily, while in other cases lack of appreciation of the facilities at the rehabilitation centres appears to be the main delaying factor.

The effect of exercises in plaster at the rehabilitation unit has been examined by two methods. In the first instance, the patients have been grouped according to the nature of the fracture and the time of final reduction. As had been anticipated, the recovery time increased in proportion to the time in plaster. Hence, when two groups are being compared, the size of the samples must be such that the mean immobilization times are constant. In the second method the fractures have been divided into four almost equal groups according to the duration in plaster, and the nature of the fracture has been ignored. The four groups comprised fractures immobilized under 3 months, 3 to 4 months, 4 to 6 months and over 6 months respectively. The analysis of the two methods has been presented in detail, as it contains the basic information required for the design of any experiment to study the effect of physical measures on the rehabilitation of these fractures.

The influence of the type of fracture in the assessment of exercises in plaster has been set out in Table IX. The results for Series A fractures are set out in section A of this table, for Series B in section B, and the combined figures for both series in section C. In Series A, the presence or absence of displacement of the fracture was noted and found to influence the findings. The mean period of immobilization for undisplaced fractures of the tibia was just over 10 weeks, whether the patient exercised in plaster or not, whereas the displaced fractures required 14 to 16 weeks in plaster. When all fractures of the tibia were subdivided into those treated by exercises in plaster at the M.R.U. and those treated elsewhere, it was found that the difference in immobilization times diminished, since the number of displaced and undisplaced fractures were



approximately equal in both groups. Even so, there is a difference of 12 days (96 - 84 days) in the mean immobilization times, but the patients treated in plaster gained another 26 days during the recovery phase. Thus, patients treated at the centre in plaster returned to duty on an average 38 days before those who arrived later. The extent to which this benefit is due to the shorter period in plaster can only be answered by increasing the number of patients in each group. There was insufficient information in the case notes of Series B patients to record the proportion of displaced and undisplaced fractures of the tibia. However, 21 fractures of the tibia were treated at the unit in plaster (Table IX B), and the mean period in plaster was almost identical with Series A (85 days), although the recovery time was 11 days longer. The patients who arrived later took 20 days longer to recover, although the time in plaster was 11 days less; but, by combining Series A and Series B (Table IX C), the time in plaster for both groups becomes approximately equal (85 and 87 days). For those patients treated with exercises in plaster the mean recovery time was 58 days, and these patients were able to return to duty approximately three weeks (22 days) before those who arrived after removal of the plaster.

A similar procedure has been adopted to determine the effect of rehabilitation in plaster for simple fractures of the tibia and fibula. It will be seen from Table IX C that the average time in plaster for the first group of patients, who were treated in plaster, was 113 days, or 13 days less than the second group of patients, who arrived later. There was a corresponding decrease of 19 days in the recovery times and 32 days in the total treatment times. Each sample contains over 50 patients, so that it is probable that the difference between the mean immobilization periods is due to earlier removal of the plasters at the rehabilitation centre. In the comparatively smaller groups of compound fractures the patients in both series treated with exercises in plaster were immobilized for considerably longer periods than the second group. This difference is due to a higher incidence of delayed union; in fact, three patients, in Series A, did not arrive at the centre for treatment in plaster until after the corresponding time had lapsed in which all the patients in the second group had had their plasters removed. It should be noted that, in Series A, certain groups of patients who were not treated at the M.R.U. in plaster recovered more rapidly than those treated in plaster.

In the last part of Table IX C, the effect of organised exercises in plaster has been determined for the three main types of fracture combined. A total of 108 patients were treated in plaster at the M.R.U. and 77 patients did not receive treatment until later. The first group recovered more rapidly, being on the average 8 days less in plaster and 18 days less in the recovery stage, so that they were fit for duty nearly four weeks (26 days) before the second group. These differences were almost identical when these two groups are compared in Series A and B separately, except that the Series A patients, treated after removal of plaster, recovered on an average 9 days more rapidly than Series B. These figures suggest that patients who undergo an organised regime of exercises in plaster return to duty considerably more rapidly. Nevertheless, it should be emphasized that small groups of patients, who do not take part in organized class exercises in plaster, do as well as the groups receiving such treatment.

At the bottom of Tables IX A and IX B, the plaster and recovery times for a number of patients treated in a caliper have been given; the results are extremely variable and patients treated by this method have therefore been omitted from further studies of the effect of organised exercises in plaster. Patients treated by skeletal traction have been included in both tables in the totals of patients sustaining simple fractures of the tibia and fibula. In Table IX B, the inclusion of two patients treated by this method has increased the mean period of immobilization above that of any of the individual groups.

The next problem to be considered was the question whether patients, who were treated for long periods in plaster, recovered more rapidly than those who arrived for treatment nearer the time for removal of plaster. Secondly, it was necessary to know if delay in arriving for rehabilitation after the plaster had been removed affected the recovery time. The patients treated in plaster were divided into two groups, those spending over 28 days at the unit and those treated for less than a month. It will be seen from Tables X and XII that this group includes patients treated from 5 to 28 days at the centre. Patients under treatment for less than 3 days before the plaster was removed could hardly be said to have received a course of exercises in plaster and were therefore included in the non-treated group. Three patients in Series A and four patients in Series B were affected in this way. The patients arriving after

removal of plaster were divided into two almost equal groups, three weeks (21 days) being the dividing line. In order to divide the patients so that the mean immobilization periods of the subgroups were as similar as possible, all fractures were analysed in four groups, each with different mean periods in plaster, viz (1) 44 - 84 days, (2) 85 - 112 days, (3) 113 - 168 days and (4) 169 - 304 days. The basic subgroups are set out in Table X, in which the effect of time of arrival at the centre is assessed. Within the limitation of the size of the samples there is reasonable agreement between Series A and B. The two series have been combined in Table XI. The recovery time increases by approximately 7 - 10 days per additional month in plaster up to six months, and probably more rapidly after this period. In Table XII, all fractures in both Series A and B have been combined irrespective of duration in plaster, and tabulated according to time of arrival at the M.R.U. Whether the series are assessed separately or together, there is no significant difference between the recovery times of patients treated for long or short periods in plaster at the unit and the times of patients arriving up to 21 days after removal of the plaster. With further delay in starting treatment, the recovery times rise very rapidly. This trend is also seen in all the subgroups in Table X. It also explains why groups of patients, who did not undergo treatment at the centre in plaster (Table IX A), did as well as those exercising in plaster, since these groups contained a high proportion of patients who arrived soon after the plaster had been removed.

Malleolar Fractures

(a) The Nature of the Fracture

In Table XIII all malleolar fractures in Series A have been listed according to the method explained in the introductory essay on classification of ankle fractures. Two objectives of classification have been successfully achieved. First, every fracture observed in the series could be accurately allocated to a group, from which recent concepts of the mechanism of production and associated ligamentous damage could be determined by reference to Table I. Secondly, neighbouring groups could be readily combined into larger classes, in such a way that the total treatment time increased in proportion to the severity of the anatomical changes. Fractures in Series B could be allocated to these larger classes, and the two series compared as in Table XIV. In the case of these fractures, the

recovery time was less constantly related to the time in plaster, than it was in fractures of the diaphysis. Hence, it is necessary to compare the total treatment times rather than the plaster times.

The various types of sprain fractures recorded in each series have been compared in Table XIV. The duration of immobilization and total treatment time for this group of fractures is shorter than for the principal fractures of the malleoli. After four to six weeks in plaster, recovery is complete in another month, but there is considerable individual variation. The long period of recovery recorded for the fractures of the tip of the lateral malleolus in Series A (54 days) and of the tip of the medial malleolus in Series B (53 days) appeared to be due to the arrival of the patient for rehabilitation some time after the removal of the plaster, whereas the remaining five patients in Series B were all treated at the Medical Rehabilitation Unit, (M.R.U.), in plaster and the mean recovery time was 25 days. McDougall (1955) described avulsion of bony outgrowths from the tibial margins and malleoli in a condition which he referred to as footballer's or athlete's ankle. Examination of the X-rays available in Series A did not reveal the presence of the more marked features described by McDougall (in particular, the exostosis of the neck of the talus), although the sites of the lesions were similar. It is possible that the lesions observed in this series may have been an early stage of this condition. Only two patients in the combined groups had sustained their injuries playing football, the commonest accidents resulting either from physical training or a simple fall or twist.

Isolated fractures in the two Series A and B (Table XIV) can be considered in three groups with similar features. Fractures of the medial malleolus and supratubercular fractures of the fibula both required immobilization for a mean period of 7 to 9 weeks, resulting in a mean total treatment time of 14 weeks (101 days) to 18 weeks (124 days). Intertubercular fractures of the fibula comprise the second group, with a mean plaster period of 5 to 6 weeks (39 days) and total treatment time of about 14 weeks. The third group contains four marginal fractures, which exhibit considerable variation in plaster and recovery times.

In Series A (Table XIII) there were 6 isolated fractures of the medial malleolus of the transverse or abduction type and one fracture of the vertical or adduction type. One patient

exhibited calification of the capsule in the region of the anterior margin of the tibia and a probable marginal avulsion fracture, and another patient had a chip fracture of the lateral malleolus. The respective total treatment times of 119 and 85 days for these fractures was within the range of the remaining fractures of this group. In addition, the presence of an avulsion fracture of the tip of the lateral malleolus in a Series B patient did not alter the treatment time compared with the rest of the group. The shortest treatment times in Series A were 55 days (plaster time 46 days) for a transverse fracture which united by fibrous union, and 56 days (plaster time 35 days) in a vertical fracture (adduction type) in Series B.

The progress of the small group of 8 supratubercular fractures of the fibula was closely related to that of fractures of the medial malleolus. The groups of intertubercular fractures made more rapid progress. Since the site of the fracture was not recorded in every case in Series B, the total of all fibular fractures probably contains several supratubercular fractures, in addition to the 3 fractures recorded in Table XIV. In one patient the plaster had been removed after 26 days, but recovery was prolonged to 97 days. The tip of the medial malleolus had also been avulsed. Of the 5 fractures in Series A (Table XIII), two were situated immediately above the tubercles, and a little higher than the most frequent site of an intertubercular fracture. The oblique fracture line was clearly seen in the anteroposterior radiograph, in contradistinction to the intertubercular type, which can be seen more readily in the lateral view. It would appear that the predominant mechanism in the production of these fractures had been abduction of the talus. The appearances of the three fractures, which had occurred just below the junction of the middle and lower thirds of the fibula, were very dissimilar.

In one patient the fracture line was similar to the abduction type at a lower level just described. In addition, a posterior marginal flake could be seen, and there were persistent aching and swelling of this region during mobilization.

In the second patient, the fracture line was almost transverse and was an example of the fracture originally described by Pott. The distal fragment had been displaced laterally from the groove on the lateral aspect of the tibia, and the proximal fragment had been

carried inwards as Pott had mentioned, so that there was side-to-side union of the two fragments. The medial joint space was increased, indicating rupture of the deltoid ligament. This fracture was not manipulated. A walking plaster had been applied after 18 days and removed after 53 days. The patient arrived at the rehabilitation unit 17 days later. On discharge after a further four weeks' treatment, he was symptom-free and fit for duties as a firefighter. He was able to run and jump without difficulty, and there was no clinical evidence of ankle instability, although radiographs showed that as much as 5° tilting of the talus into abduction had persisted.

The direction of the fracture line in the third patient was similar to that of the "mixed oblique" intertubercular type. The prolonged period of immobilization (93 days) was due to a gap of $\frac{1}{4}$ inch (0.6 cm.) between the fragments, since posterior displacement of the lower fragment had not been corrected.

There were no basal fractures of the fibula in Series A; one example was recorded among the Series B fractures. The 15 intertubercular fractures in Series A could be divided into two groups, depending on whether or not the initial displacement had been considered to be sufficient to warrant manipulation of the fracture. Five fractures were reduced under a general anaesthetic. The mean plaster time was 45 days, and the mean total treatment time 87 days. The remaining ten fractures were not manipulated before being immobilized in plaster. Two of these patients developed post-traumatic pes valgus during mobilization. The mean total treatment times for these patients were 144 and 154 days respectively. The mean plaster time for the remaining 8 patients was 37 days. The total treatment time for these fractures (89 days) is similar to the corresponding time for the displaced fractures (87 days), in which a greater degree of ligamentous damage to the anterior inferior tibiofibular ligaments and deltoid ligament would have been expected. One of the manipulated fractures was, in fact, complicated by an avulsion fracture of the tip of the medial malleolus. The appearance of the fracture line varied considerably in obliquity, and in some cases posterior angulation at the fracture site had persisted. There was no suggestion in the trends observed that these differences in obliquity, angulation or amount of initial displacement influenced the progress of intertubercular

fractures; the anatomical site alone was a sufficient guide to grouping.

Comparison of the totals of all fibular fractures and all isolated fractures in Series A and B (Table XIV) shows that there is close agreement between the two series as to the mean plaster and total treatment times. The figures in brackets in Series B indicate that one patient, whose rehabilitation was prolonged by a posterior tibial nerve palsy, was excluded from the totals for mean recovery and total treatment times, although included in the figures for immobilization in plaster.

Bimalleolar and trimalleolar fractures (Table XIV) form a closely related group, requiring 8 to 12 weeks in plaster and another 8 to 15 weeks' mobilization. A trend in the figures for fractures of the posterior margin of the tibia and lateral malleolus suggests that these fractures can be rehabilitated more rapidly than other bimalleolar and trimalleolar fractures. The difference may amount to two or three weeks but can only be assessed in a larger series. Details of the anatomical site of these fractures in Series A are given in Table XIII. In one of the bimalleolar fractures, the vertical fissure fracture of the medial malleolus was accompanied by a transverse crack across the fibula nearly one inch (2.5 cm.) above the inferior tibio-fibular articulation. Fracture of the fibula at this level due to adduction violence is extremely rare, the usual site being across the lateral malleolus. It will be seen that transverse fractures of the medial malleolus were more commonly accompanied by oblique supratubercular fractures of the fibula of the abduction type than by helical intertubercular or supratubercular fractures produced by lateral rotation violence. The latter fractures are more commonly combined with fractures of the posterior margin of the tibia, as Lauge-Hansen has suggested from his experimental observations. However, both the intertubercular fractures of the fibula were complicated by avulsion fractures of the tip of the medial malleolus as well, suggesting that some damage to the medial ligaments had occurred. On the other hand there was no evidence of similar changes accompanying the supratubercular fractures, in which a similar mechanism was to be expected.

The compression fractures present individual problems which defy classification.

One patient sustained fractures of both malleoli, comminution of the anterior margin of the tibia, and flake fractures of the upper articular surface of the talus following a parachute jump. When the plaster was removed after 13 weeks immobilization, he was unable to walk except on the outer border of his foot owing to 20° persistent adduction tilt of the talus. Arthrodesis of the ankle was eventually necessary, although he did not complain of any pain in his ankle.

The three remaining patients returned to full duty without symptoms, but recovery time was prolonged.

The epiphyseal separation fractures form another small group, the rehabilitation of which is similar to that of isolated fractures. Subdivision into fracture separations of the individual fibular and tibial epiphyses results in subgroups, which are too small to show definite trends.

Finally, in both series there is a small group of miscellaneous fractures. In Series A, osteochondritis dissecans of the upper articular surface of the talus was discovered during mobilization of the ankle joint following an intertubercular fracture of the fibula.

The second patient had sustained an isolated fracture of the lateral malleolus, which had united in a good position after about 10 weeks in plaster. He was referred to the M.R.U. some five months after the plaster had been removed, because he was still walking with his leg laterally rotated. He could not be persuaded to correct his abnormal gait. He was depressed and apathetic, and it was concluded that there was a hysterical basis for his limp, which eventually resulted in invaliding action being taken. It is possible that early treatment at a rehabilitation centre, with the teaching of the correct method of walking in plaster, might have prevented this unsatisfactory result. The three miscellaneous fractures in Series B included (a) a fracture of the lateral malleolus (probably intertubercular), which was treated by elastoplast for 46 days, the patient being able to return to full duties 7 days later, and (b) two fractures of the medial malleolus (isolated and bimalleolar respectively), which required delayed reduction and screwing for non-union. The second patient was treated in plaster for a total of 277 days and required another 155 days mobilization. He was off duty for well over a year.

Analysis of the Accidents resulting in Malleolar Fractures

The incidence of the various methods by which the patients in Series A sustained their fractures is shown in Table XVI. In addition, the mode of injury was analysed in each individual group of fractures recorded in Table XIII; it was found to be evenly distributed among the various types of fractures. A comparison has also been made between the percentage incidence of the methods of injury in malleolar and in diaphyseal fractures. In malleolar fractures the incidence of soccer injuries is one fifth of the total, whereas in diaphyseal fractures soccer accounts for nearly half the number of all fractures. Rugger injuries are responsible for three per cent. of shaft fractures and 13 per cent of ankle fractures. Wynn Parry (1956) found in a series of patients, admitted to the M.R.U.s. at Chessington and Collaton Cross in the three years 1953/55, that the ratio of soccer to rugger injuries in ankle fractures was eight to one. He also found that, in malleolar and diaphyseal fractures, motor cycle accidents were more frequently the cause of injury than soccer.

(b) The age of the Patient

The mean duration of immobilization and total treatment time have been recorded in Table XVI, in which isolated, bimalleolar and trimalleolar fractures have been divided into three age groups, viz. 17 to 19 years, 20 to 24 years, and 25 to 44 years. For isolated fractures, both the plaster time and the total treatment time are similar in the three age groups, but, for bimalleolar and trimalleolar fractures, there is a slight tendency for the total treatment time to increase with age. The figures are too small for an accurate assessment of the amount of increase, which probably amounts to 7 weeks between the youngest and oldest age groups.

Of the patients who had received epiphyseal separation fractures, three were over 16 years, one over 17 years, 4 over 18 years and one over 19 years of age. The lower tibial epiphysis has usually united by the age of 19 years, but in this case the physical development was that of a boy of 16 years.

(c) The Method of Reduction and Fixation of the Fracture

The initial treatment of the 61 malleolar fractures in Series A was carried out in fifteen different civilian hospitals and eight different Service hospitals. In addition, five patients were referred directly after treatment in Station sick-quarters. The methods of reduction and fixation employed in the various fracture groups (number of patients in brackets) were as follows:-

Sprain fractures (6): all patients were immobilized in plaster without manipulation after the initial swelling had subsided.

Isolated fractures of the medial malleolus (7): Four patients were immobilized in plaster without manipulation. In only one patient was weight-bearing delayed for as long as five weeks. The remaining three patients were treated by open reduction and screwing of the medial malleolus within the first week. Weight-bearing was delayed from four to six weeks. Although the time in plaster was similar, these patients had a slightly longer total treatment time than the remainder of the group. Fibrous union occurred in one of the patients treated by plaster alone. The fracture was clinically stable, and it was decided not to interfere. He was able to return to full duty without symptoms or loss of ankle movement. In the remainder, union in good position was achieved.

Isolated supratubercular fractures (5): Of the fractures in this group only two have been manipulated under a general anaesthetic. In four cases the date of application of the walking plaster varied between the 5th and 18th day. In one patient with a fracture at the lower site, the ankle tended to give way into inversion on running, and this was controlled by fitting an outside wedge of $\frac{3}{16}$ inch (0.4 cm.) on the heel of his shoe. The remainder attained a state of fitness which allowed them to undertake heavy duties without difficulty.

Isolated intertubercular fractures (15): Five patients required manipulation under a general anaesthetic. The remainder were immobilized in plaster immediately. A walking plaster was applied in one third of the patients during the first week, in another third during the second week, and in the remaining third during the third week. The position of the fragments after reduction or injury was excellent in all except three patients, in whom slight postero-lateral displacement persisted.

Isolated posterior marginal fracture (1): This fracture was manipulated twice under a general anaesthetic before good positioning was achieved. A walking plaster was applied after three weeks.

Bimalleolar fractures of medial and lateral malleoli (7): In two patients no attempt had been made to reduce the fracture, and the talus remained persistently adducted - in one patient to the extent of 8° . These patients were immobilized for ten and fifteen weeks respectively, but they both made a good recovery in eight to nine weeks, so that they could run and jump with minimal discomfort. The reduction in the remaining patients had been satisfactorily achieved as follows:-

Manipulation under general anaesthetic:	2 patients
Open reduction and screwing of medial malleolus:	1 patient
Open reduction and fixation of medial malleolus with a hook plate screwed to the lower tibial shaft:	1 patient
Open reduction and periosteal suturing of the fracture:	1 patient

Two patients remained non-weight-bearing until the plaster was removed. In the remainder a walking plaster had been applied within the first month.

Bimalleolar fractures of the lateral malleolus and posterior margin (7):

Four fractures were manipulated under a general anaesthetic and three immobilized in plaster without manipulation. One intertubercular fracture which had been manipulated showed a slight lateral displacement of the lateral malleolus that had persisted. The recovery stage was prolonged owing to a tendency for the ankle to give way as a result of lateral ankle instability. This was eventually controlled as the ankle became stronger, and the patient was able to return to duty as a physical training instructor without symptoms after 13 weeks mobilization. On the other hand a patient who had sustained a supratubercular fracture which had not been manipulated and showed slight postero-lateral displacement of the lower end of the fibula, with tilting of the talus into abduction, was rehabilitated more rapidly without any tendency of the ankle to give way. Satisfactory reductions had been achieved in the remainder. One patient was not allowed to weight-bear in plaster. In the remainder a walking plaster had been applied after 2 to 3 weeks.

Trimalleolar fractures (4): As in a number of the previous groups one fracture had been incompletely reduced: the talus remained abducted and laterally rotated. In addition, fibrous union of the medial malleolus occurred, and the patient returned to his unit for duties which were modified on account of persistent pain, for which operation was considered at a later date. All the fractures had been manipulated under a general anaesthetic, but in two cases open reduction with periosteal suturing and screwing of the medial malleolus was necessary on the 3rd and 19th day respectively. The unreduced fracture was put in a walking plaster after three weeks, while in the remainder weight-bearing was delayed for 8 weeks or until the plaster was removed.

Compression fractures (2) and Miscellaneous fractures (3): These fractures have been detailed above.

Epiphyseal separations (5): Three of these fractures were reduced under a general anaesthetic; the others were treated in plaster only. In one patient the lower tibial epiphysis had been split vertically into two halves with $\frac{1}{4}$ " splaying of the fragments. He developed an ankle effusion during mobilization, but he had made a full recovery within 6 weeks. Another patient with a posteriorly displaced tibial epiphysis developed ankle instability during the recovery stage, which was probably due to a partial tear of the lateral ligaments of the ankle. The methods of treatment adopted can be summarised as follows:-

Plaster only	31 patients
Manipulation under general anaesthetic and plaster	22 patients
Open reduction and screwing of the medial malleolus	5 patients
Open reduction and periosteal suturing of the medial malleolus	2 patients
Open reduction and fixation of the medial malleolus with a hook plate	1 patient

The method of reduction did not appear to influence the duration of immobilization in plaster within each fracture group. Recovery times were slightly prolonged in fractures of the medial malleolus, which had been submitted to open reduction. The time of application of a walking plaster was extremely variable, and depended on the views of the medical officer who was supervising the treatment. The presence of potential diastasis did not appear to influence the

decision to delay weight-bearing. Delayed weight-bearing occurred more frequently with fractures of the medial malleolus, both unimalleolar and bimalleolar, than with supratubercular fractures. The data from Series B fractures were insufficient to confirm or deny these observations.

(d) The Observer Variation in Assessment of Time for Removal of Plaster

It is difficult to assess observer variation quantitatively. Too early removal of the plaster may result in prolonged rehabilitation owing to pain in the region of the ankle. On the other hand, prolonged immobilization may be unnecessary and prevent early return to duty.

The first two patients with intertubercular fractures in Series A illustrate this problem. Both patients were 19 years old. The fractures were undisplaced, and were immobilized in plaster immediately. In the first patient the plaster was removed after 14 days. He was still complaining of pain in his ankle, was limping badly, and was unable to run on admission to the rehabilitation centre 10 weeks later. A further 5 weeks' treatment was necessary. The total treatment time was 17 weeks (121 days).

The second patient had sustained a long oblique fracture, for which the military surgeon had suggested a period of 10 weeks in plaster, presumably on account of potential diastasis. He arrived at the rehabilitation centre in a walking plaster where he spent 2 days, during which time he was taught to walk correctly in plaster. He then returned to his unit for full-time clerical duties. He was re-admitted to the rehabilitation centre 6 weeks after his injury, when the plaster was removed and the fracture found to have united satisfactorily. He was able to return to duty again within 3 weeks, being able to walk, run and jump without symptoms. The total treatment time from the date of his fracture was 9 weeks (64 days), but he was able to undertake productive work for one month of this period.

The second example concerns two supratubercular bimalleolar fractures in which the medial malleolus had been fixed, in one patient by a screw and in the second by a screw and hook plate. In the first patient the plaster had been removed after 3 weeks, and he remained non-weight-bearing on crutches until the 12th week (85 days).

Treatment at the M.R.U. started during the 8th week. Recovery was very slow owing to marked oedema of the ankle, and he was still walking and running with a slight limp on return to modified duties as a physical training instructor after a total treatment time of 30 weeks (210 days).

The second patient was treated in plaster and was allowed to weight-bear after 26 days. The plaster was removed after 54 days, but he slipped in the ward and re-fractured his ankle. The plaster was re-applied, and he remained non-weight-bearing until he arrived at the M.R.U. after 21 weeks (148 days). Within 10 weeks he could walk 10 miles without symptoms, and his only disability was a slight limp on running. The total treatment time was again just over 30 weeks.

There appears to be an ideal period of immobilization in plaster for each individual fracture. Moreover, there is no evidence to suggest that early non-weight-bearing mobilization of malleolar fractures shortens the total treatment time, even when whole-time rehabilitation facilities are available.

(c) The Influence of Treatment at the Rehabilitation Centre while the Fracture was in Plaster

All malleolar fractures in both series were divided into two groups according to the duration of immobilization in plaster, namely, (1) up to 7 weeks (49 days), and (2) 7 to 16 weeks (50 to 112 days), with the following exceptions:-

<u>Series A:</u> osteochondritis dissecans	1 patient
delayed recovery owing to psychiatric disturbance	1 patient
arthrodesis of ankle	1 patient
under-immobilized bimalleolar fracture, with prolonged recovery time	1 patient
bimalleolar fracture immobilized for 148 days	1 patient
<u>Series B:</u> fracture treated with elastoplast	1 patient
posterior tibial nerve palsy	1 patient
compression fractures	2 patients
bone graft for delayed union	2 patients

The remaining patients were grouped according to the duration of immobilization in plaster, as follows:-

<u>Series A:</u>	under 49 days in plaster	26 patients
	over 49 days in plaster	<u>30 patients</u>
		<u>56 patients</u>
 <u>Series B:</u>	 under 49 days in plaster	 40 patients
	over 49 days in plaster	<u>36 patients</u>
		<u>76 patients</u>

Unfortunately, Series A and B differ in that Series B contained no fewer than 15 patients with isolated fractures of the fibula, which were immobilized for over 49 days in plaster. Series A included only 6 such fractures, four of which were supratubercular. Examination of the individual case histories in Series B suggested that many of these fractures were over-immobilized. Recovery in some of these cases was very rapid - in 2 cases under 10 days. On the other hand, the corresponding group of patients in Series A contained a much higher proportion of bimalleolar and trimalleolar fractures.

In Table XVII the two groups have been subdivided according to whether the patients (1) were treated in plaster at the M.R.U. for over 28 days, (2) were treated in plaster at the M.R.U. for 5 to 28 days, (3) had arrived at the M.R.U. within 14 days of removal of plaster, or (4) had arrived at the M.R.U. over 14 days after removal of plaster.

The patients who had their plaster removed within 3 days of their arrival at the M.R.U. are included in the third group, since it was considered that they were not at the M.R.U. long enough to benefit from class exercises.

In the patients treated for under 7 weeks, the only group which differs from the rest is the one containing patients who arrived at the M.R.U. more than 14 days after removal of plaster. In these patients the total treatment time was 15 to 17 weeks (108 to 119 days). In the remaining groups the average treatment time was $9\frac{1}{2}$ to 13 weeks (66 to 89 days).

The same pattern was seen in the group of patients treated for over 7 weeks in plaster. The patients who arrived more than 14 days after removal of plaster required on the average about one month longer under treatment. The differences were not so clear as in those treated for less than 7 weeks in plaster because (1) Series A contained a higher proportion of more serious fractures, and (2) Series B included a high proportion of simple fractures which had been over-immobilized.

The two series have been combined for analysis in Table XVIII. The average total treatment time for patients who were in plaster for less than 7 weeks is 11 weeks (77 days) if treated at the M.R.U. in plaster, and 13 weeks (92 days) if treated elsewhere. Among the 32 patients who did not take part in an organized programme of exercises in plaster, there were 7 patients who had their plaster removed on arrival at the centre. The recovery time for these patients was similar to that of patients who took part in the organized programme of exercises in plaster. As demonstrated in Table XVIII, the treatment time for patients who arrived at the centre more than 14 days after removal of plaster was very much greater, the mean for the two series being 16 weeks (112 days).

For patients who were in plaster for 7 to 16 weeks, the average total treatment time was 13 weeks (92 days) if treated at the M.R.U. in plaster, and 22 weeks (154 days) if treated elsewhere. Five patients had their plasters removed shortly after arrival at the rehabilitation unit. The mean treatment time for the patients in the combined series, who arrived at the centre more than 14 days after removal of plaster, was 25 weeks (172 days).

In Table XIX, all malleolar fractures in both series have been grouped according to time of arrival at the M.R.U. The trend shown in the previous tables is confirmed, but the numbers are larger.

Conclusion. As was demonstrated for fractures of the shafts of the tibia and fibula, there is no evidence that an organized programme of exercises in plaster accelerates recovery of function. The vital period for rehabilitation is the first 2 to 3 weeks after the plaster has been removed.

THE MOBILIZATION PERIOD

It has been possible to study the recovery of joint and muscle function in some detail from the proformas of patients in Series A. Owing to lack of consistent detail in the case records a similar analysis of the Series B fractures could not be undertaken.

1. Recovery of Knee Movement after Diaphyseal Fractures

In 41 patients, who had been treated at the M.R.U. in plaster, the joint range had been measured immediately after the plaster had been removed. From Table XX, it will be seen that the range of knee extension remained constant, whether the fracture had been immobilized for up to 12 weeks (84 days) or over 6 months (169 days). On the other hand, the amount of knee flexion which could be achieved decreased as the length of plaster period increased. The difference between the mean extent of knee flexion (111°) for patients immobilized under 12 weeks and the knee flexion (131°) of patients in plaster for over 6 months is statistically significant ($P=0.017$). Full extension of the knee was regained in all but 3 patients; the limitation of movement amounted to 5° in 2 patients, and 10° in one patient, who had a cartilage lesion complicating the fracture.

The rate of recovery of knee flexion has been estimated by recording the number of patients who had regained 90° , 70° , 50° and 40° of movement during each week following removal of the plaster at the M.R.U. As in previous tables, the patients have been divided into four groups according to the duration of immobilization in plaster. The results of this analysis in 54 patients have been set out in Table XXI. The majority of patients, whose fractures were immobilized for less than 3 months (84 days), had regained 90° and 70° of flexion within the first two weeks and 50° during the third week. After more prolonged immobilization these stages were reached later and scattering of the observations became more pronounced, especially as flexion neared completion. Thus, after 6 months (over 169 days) in plaster, half the number of patients (50%) had not gained 90° flexion until the 4th post-plaster week, and the majority of patients (90%) not until the 6th week. The time taken for half (50%) and the majority (90%) of patients to reach each stage of knee flexion provides a concise measure of this distribution, and has been utilized in Table XXII. Of the 54 patients studied, 3 patients had not regained 50° knee flexion and 16 patients 40° flexion by the

time they returned to duty. Consequently, the size of each group of patients in this Table is reduced as the range of movement becomes greater. Limitation of movement at the end of treatment was due to 3 factors; in the first instance, some patients had progressed so rapidly in other respects that they could be returned to duty before full movement had been achieved. Secondly, joint stiffness following prolonged immobilization was a major contributing factor; the 3 patients who did not obtain 50° flexion had been immobilized for more than 5 months (140 days). Finally, there was considerable variation in the extent to which the normal knee joint could be flexed, in four cases being limited at 42° to 45°, although in the majority 30° to 35° was finally recorded. The arbitrary figure of 40° was chosen to represent full flexion, being the degree of movement which the majority of patients could be expected to achieve.

The range of movement attained immediately after removal of the plaster was independent of the type of fracture sustained, although it was influenced by the duration of immobilization of each group. The range of movement recorded on removal of plaster was as follows (cf. Table XX):-

Simple fractures of the Tibia alone (mean, 83 days in plaster)	171° to 114°
Simple fractures of the Tibia and Fibula (mean, 113 days in plaster)	173° to 120°
Compound fractures of the Tibia and Fibula (mean, 161 days in plaster)	173° to 126°

Table XXI was redrafted to show the distribution of the rates of recovery of the three types of fracture; but there was no evidence to suggest that the type of fracture influenced the rate of recovery of joint movement.

2. Recovery of Movement of Ankle and Foot after Diaphyseal Fractures

The mean range of ankle movements on removal of plaster in the 41 patients treated at the M.R.U. in plaster is shown in Table XX. The range of dorsiflexion was not influenced by the plaster time (variation of means, 87° to 89° in the 4 groups). Plantar flexion was slightly greater in those patients immobilized for less than 84 days (128°) than in the remaining groups (117° to 123°), but the size of the samples is too small for the differences to become significant.

The rate of recovery of ankle movement has been summarized in Table XXII. The distribution of patients, attaining a certain range of movement during each post-plaster week, is similar to that for recovery of knee flexion detailed in Table XXI, but the scatter of observations is increased; this is reflected in a greater difference between the figures for the weeks in which half the number and the majority of patients reached each stage as shown in Table XXII. The increased scatter is probably the result of the more marked variation in the range of movement of the normal ankle joint. It was shown in Table XXI that, in the case of the knee joint, the normal range of which is fairly constant, the rate of recovery of flexion slowed up as the full range was approached; the distribution of patients became more scattered at the same time. But in the normal ankle joint full dorsiflexion was found to vary from 86° to 65° , and plantar flexion from 135° to 160° . Although in many patients the range of normal ankle movement remains constant during a course of rehabilitation, in one patient an increase of 18° in range of plantar flexion (from 142° to 160°) was observed. Consequently, when the injured ankle was compared with the normal, limitation of plantar flexion was 5° at the time of removal of the plaster but had increased to 10° on completion of treatment six weeks later (actual increase 138° to 150°). Comparison of the injured ankle with the normal is an unreliable method of registering progress. Owing to the constitutional pliability of the ankle and foot, the figures for the rate of recovery in 90% of the patients are an unreliable guide to the effect of other factors such as the plaster time, which is best measured at the 50% level. The lower limit of normal plantar flexion (135°) was reached within the first post-plaster week in 50 per cent. of patients immobilized for less than 3 months (84 days), but not until the 5th week when the plaster time was over 6 months (169 days). Nine of 53 patients had not obtained this amount of movement before return to duty.

It might have been expected that all patients would have attained 90° dorsiflexion of the ankle within the first week out of plaster. However, a number of patients arrived at the M.R.U. with the ankle joint immobilized in a considerable degree of plantar flexion. Although this was corrected wherever possible, limitation of dorsiflexion persisted after the first post-plaster week in 8 patients. The lower limit of normal plantar flexion (86°) was reached by all patients except one; in this patient dorsiflexion was limited at 90° owing to extensive scarring in the region of extensor hallucis longus tendon. Prolonged immobilization

appeared to have less effect on dorsiflexion than plantar flexion.

In Table XXIII the range of supination and pronation of the immobilized foot has been compared with the normal foot at the time of removal of the plaster. The range of pronation was more frequently greater than that of supination, and this tendency was found to persist during the recovery period. The rate of recovery of supination and pronation has not been detailed, since these are relative measurements depending for accuracy on a constant range of movement in the normal foot, a concept which has been disproved from absolute measurements of the range of movement of the ankle.

The range of knee and ankle movements was recorded in 31 patients, who arrived at the M.R.U. after removal of the plaster. It was not possible to plot with accuracy the distribution diagram of the rate of recovery of these patients, as the arrival of some patients at the centre was delayed for several weeks. For knee flexion, the estimated rate of recovery for 50% and 90% of the patients appeared to be almost identical with that of patients treated at the M.R.U. in plaster. The trend for ankle movements was ill-defined on account of scattering, but the right hand side of the distribution diagrams was monopolized by patients, who had arrived at the M.R.U. later than the third post-plaster week. These patients appeared to be taking two to three weeks longer to pass each stage than those who had arrived earlier. No patient, however, failed to reach 85° dorsiflexion, and all but 4 reached 135° plantar flexion.

3. Range of Movement of Ankle and Foot after Malleolar Fractures

The mean range of ankle movements on removal of plaster at the M.R.U. in 27 patients, who had sustained ankle fractures, is shown in Table XXIV. All fractures of the ankle region, including sprain fractures and epiphyseal separations, are contained in the groups comprising fractures immobilized for less and for more than 7 weeks (49 days). The range of dorsiflexion and plantar flexion was constant in these latter groups, as well as in the groups containing the individual malleolar fractures.

The rate of recovery of ankle movements after each type of ankle fracture is summarized in Table XXV. The distribution of patients during recovery is of the same pattern as demonstrated after diaphyseal fractures. In spite of the small groups there appears to be some justification for separating the

intertubercular fractures from the remaining isolated fractures. The latter group (containing supratubercular fractures and fractures of the medial and posterior malleoli) is in some respects similar to the bimalleolar and trimalleolar group, particularly with regard to delay in plantar flexion, since half the patients took 4 to 6 weeks to gain 135° of plantar flexion against 2 weeks after intertubercular fractures. As these groups contained less than 10 patients, the figures for the majority of patients (90%) measure the range of distribution of all the patients. In the two groups containing all ankle fractures immobilized over and under 7 weeks (49 days) the influence of the addition of sprain fractures and epiphyseal separations can be seen, since recovery after these injuries was rapid. In contrast, the final group of malleolar fractures proper shows, with regard to recovery of plantar flexion, an almost identical distribution to that of diaphyseal fractures immobilized over 6 months (169 days); in both cases half the patients reached 135° plantar flexion in the 5th post-plaster week. All patients achieved the upper limit of normal dorsiflexion (85°) before discharge. In three patients, all of whom had sustained supratubercular fractures (one complicated by fracture of the posterior margin of the tibia) plantar flexion on discharge was 3° to 8° short of the normal lower limit.

The range of supination and pronation at the time of removal of plaster is shown in Table XXIII. Again, the range of pronation was more frequently greater than that of supination. The difference is larger than after diaphyseal fractures, since the mode for pronation is more than $\frac{3}{4}$ of the normal against $\frac{3}{4}$ of the normal for diaphyseal fractures, the mode for supination being the same in both groups.

The range of ankle movements was recorded in 20 patients who arrived at the M.R.U. after removal of the plaster. As demonstrated after diaphyseal fractures those patients, who arrived after the 2nd post-plaster week, were distributed over the right hand side of the distribution diagrams, and, on the average, passed each stage about 4 weeks later than those who arrived earlier. All patients reached 85° dorsiflexion, and only one patient failed to reach 135° plantar flexion.

4. The Rate of Recovery of Walking, Running and Ability to stand on the Toes

The five tests of function detailed in Table XXVI have been selected from a larger number of tests recorded on the

proformas. These tests are the most suitable means of indicating return of agility. The plaster immobilization groups have been arranged in this table so as to keep the plaster time as constant as possible, while preserving groups of at least 10 patients. Hence, for diaphyseal fractures, the first two immobilization groups used previously have been combined. For fractures immobilized under 4 months, therefore, patients treated for more than 28 days at the M.R.U. in plaster were on the average able to stand readily on the toes of the injured leg without support 11 days before patients in the other two groups. The remaining tests could be performed at about the same time after removal of the plaster in all three groups. The fourth group of patients arriving over 21 days after removal of the plaster has been omitted at this stage owing to the small size of the sample. When diaphyseal fractures are considered as a whole (Table XXVI), and allowance is made for variation in the plaster time, there is close agreement between the first three groups of patients with regard to the time taken before these tests could be performed. Patients arriving over 21 days after removal of the plaster took very much longer. Although the mean plaster time of this group (148 days) is considerably greater than the other groups, it is possible to compare this group with fractures immobilized for more than 4 months and treated at the M.R.U. for more than 28 days in plaster. The mean plaster time of this group is 146.5 days. The later arrivals take on an average at least 17 to 40 days longer to reach each stage, compared with the plaster-treated group. The + sign indicates that approximately 10% of the patients did not reach this stage before discharge, and the figures in these columns relate to the time taken by the remaining patients. Consequently, the difference between the last two groups is greater than the figures indicate, and it would appear that the patients in the delayed arrival group were not as a whole so fit on discharge as the remaining patients, since some patients failed to perform every one of the tests of function.

The effect of increasing periods of immobilization on patients treated at the M.R.U. in plaster is shown in Table XXVII. Both with diaphyseal and malleolar fractures, the ability just to be able to stand on the toes of the injured leg alone⁽⁵¹⁾ and to walk with even paces and minimal limp⁽⁵²⁾ occurs about the same time; the association is very close with malleolar fractures. Ability to run with even steps and minimal limp⁽⁵³⁾ takes about a week longer than ability to stand readily on the toes of the injured leg⁽⁵²⁾; normal walking⁽⁵⁴⁾ occurs about the same time but is

more variable. With diaphyseal fractures in plaster less than 3 months walking with minimal limp occurred about 30 days after removal of the plaster, ability to stand easily on the toes of the injured leg a week later, and running with minimal limp and normal walking a week later still. Patients from 4 to 6 months in plaster took only one to two weeks longer to reach these stages, but after over 6 months in plaster the delay was much greater (5 to 11 weeks).

For patients with malleolar fractures immobilized under 7 weeks (Table XXVIIb), the times for walking and running with minimal limp were 3 weeks (19 days) and 4 weeks (27 days) respectively, but after 7 weeks in plaster these times were doubled (36 and 50 days). Analysis of the effects of the type of ankle fractures on the time taken to perform these tests (Table XXVIIc) showed that both the sprain fracture and epiphyseal separation groups recover more quickly than patients who sustain a major fracture. In spite of differences in the mean immobilization times, patients with both isolated and bimalleolar fractures were able to walk with minimal limp^(w) after 4 weeks mobilization, but the more advanced tests could be performed 1 - 2 weeks earlier after isolated inter-tubercular fractures than after fractures of the medial malleolus or supratubercular and bimalleolar fractures.

The effect of time of arrival at M.R.U. on performance of these tests after malleolar fractures is shown in Table XXVIII. In spite of the small samples, there is a close correlation between the performance of patients in the first three plaster groups. The patients treated for more than a month at the M.R.U. in plaster were able to walk with minimal limp and stand on their toes a week to 10 days before the remainder, but this difference is not seen in the time for normal walking and running. In patients whose arrival was delayed over 14 days after removal of plaster, the time taken to be able to perform each of these tests was twice as long as for the remaining groups.

5. Oedema

In 97 patients with diaphyseal fractures, clinical oedema (graded + or ++) was seen in 21 patients (23%). The proportion in the 61 patients treated at the M.R.U. in plaster was 15 per cent. A greater incidence was recorded in those groups of patients who (a) arrived after the removal of the plaster (33%), (b) had compound fractures (33%), or were treated by open reduction (30%). The effect of longer periods in plaster was small (under 3 months

in plaster, 17%; over 6 months in plaster, 21%). Oedema developed in a large proportion (57%) of the 14 patients, whose radiographs showed marked osteoporosis with patchy decalcification of the tarsus at the time of removal of the plaster. This association was most constant in those patients, who were in plaster for less than six months. These observations suggest that osteoporosis is not always related to prolonged immobilization, but may be a constituent of the reflex vascular changes, which result in a greater tendency for oedema to develop in certain individuals.

In the malleolar fracture groups, clinical oedema was not seen in patients, who had sustained sprain fractures or epiphyseal separations. In the remaining groups, nine patients (20%) developed oedema. The patients were almost evenly distributed between those treated in plaster at the M.R.U. and those arriving later. Gross oedema (++) was present in only one patient. Patchy osteoporosis of the tarsus could be seen in the radiographs.

Oedema was most frequently recorded in the first and second post-plaster weeks. In most patients only a trace remained after 7 to 10 days treatment. However, in those patients who arrived at the M.R.U. later than the 3rd post-plaster week, recovery tended to last weeks or months. Slight swelling of the leg (in groups recorded as oedema "trace", or oedema after exercise) was sometimes observed for the first time when the patient became more agile in the later stages of treatment.

6. Joint and Soft Tissue Lesions

The incidence of joint and soft tissue lesions complicating the 97 diaphyseal and the 61 malleolar fractures was as follows:-

	Diaphyseal Fractures (per cent)	Malleolar Fractures (per cent)
(a) Ankle effusion	8	4
(b) Knee effusion	11	-
(c) Injury to ligaments of the knee	6	-
(d) Ulcer	3	3
(e) Pes valgus	17	25
(f) Metatarsalgia	11	10
(g) Tendon Lesions	12	1
(h) Lateral popliteal palsy	1 patient	1 patient

In addition, two patients with malleolar fractures complained of persistent symptoms due to lateral ankle instability.

The knee and ankle effusions were transient episodes, which did not usually require separate treatment. The ulcers, however, which originated either from failure of wounds to heal under plaster or from pressure sores during the early stages of treatment, inevitably resulted in several weeks delay in recovery. In most of the patients affected, the pes valgus deformity was mild, and lasted only a week or two during treatment. In the severer cases several possible causal factors were evident, such as (1) medial angulation of the tibia, (2) subtaloid adhesions, and (3) lack of balance between inversion and eversion of the foot. This third factor sometimes resulted from lesions of the tibialis anterior tendon. The tendon lesions affected the following muscles:-

Flexor hallucis longus	1 patient
Extensor hallucis longus	7 patients
Tibialis Anterior	4 patients

The resultant disability due to these tendon abnormalities varied from nil to a marked limp, and, in one patient, a plastic repair was eventually necessary.

Six of the patients with diaphyseal fractures were invalided. The reasons for invaliding were:-

Post-traumatic osteodystrophy	2 patients
Grossly angulated fracture	1 patient
Cartilage lesion (operation refused)	1 patient
Brachial plexus injury	1 patient
Unstable knee	1 patient

All the patients with malleolar fractures were returned to duty, apart from one patient who was re-admitted to hospital for further surgical treatment.

7. The Influence of Progression from the Early to the more Advanced Exercise Programme

After transfer from one programme of class exercises to a more advanced routine, most patients continued to maintain a constant rate of recovery of power and range of the movements of

the ankle and foot. In approximately 10 per cent of patients, however, there was a sudden increase in the range of ankle dorsiflexion and plantar flexion. This change was observed only half as frequently during the recovery of supination and pronation. Reduction in the range of ankle dorsiflexion and plantar flexion was also observed in approximately 10 per cent. of patients. This regression is unlikely to be due to chance for two reasons. In some patients the decrease amounted to as much as 10 degrees in contrast to a steady increase recorded previously. Secondly, complications, such as pain in the ankle or forefoot, oedema, ankle effusion or knee symptoms, frequently developed at the same time. The recovery of supination and pronation was rarely affected in this manner, but pes valgus sometimes developed at this stage. These changes appeared to be a response to excessive activity while weightbearing. Fortunately, with close supervision the regression was usually transient, and it was rarely necessary to return a patient to a less advanced class.

PHYSIOTHERAPY, HYDROTHERAPY and OCCUPATIONAL THERAPY

In several patients physiotherapy, hydrotherapy or remedial occupational therapy was prescribed in place of one or more periods of group exercises. The number of patients in Series A, treated by these alternative methods, was as follows:-

	With fractures of the tibia and fibula	With malleolar fractures
Physiotherapy	<u>58</u> patients	<u>34</u> patients
Hydrotherapy	11 patients	7 patients
Remedial Occupational Therapy	<u>11</u> patients	<u>10</u> patients
TOTAL	<u>80</u> patients	<u>51</u> patients
Number of patients receiving more than one alternative treatment (-)	16 patients	13 patients
No alternative treatment (+)	<u>33</u> patients	<u>23</u> patients
TOTAL	<u>97</u> patients	<u>61</u> patients

Approximately half the Series B patients in each fracture group received physiotherapy as an alternative to class exercises. Only 5 patients were given hydrotherapy or occupational therapy.

The three principal indications for the ancillary methods of treatment adopted in Series A patients were:-

- (1) to control oedema as rapidly as possible
- (2) to increase the range of joint movement and muscle power
- (3) to treat foot complications, particularly metatarsalgia.

In this series methods of increasing joint range and muscle power were examined with the object of selecting the most promising treatments for further study. A controlled study of two methods of treatment was rejected since only relatively small groups of patients were available. Consequently, the possibility that an alternative method of treatment was effective could only be considered when the rate of recovery altered dramatically when the new treatment was started.

Hydrotherapy No patient improved more rapidly while having hydrotherapy than during the previous period of class exercises alone. On the other hand, when one patient was given a more advanced programme of class exercises (Early Legs Class), the range of ankle movements increased more rapidly than in the previous weeks, during which treatment included Hydrotherapy.

Occupational Therapy A treadle was operated by the patient in order to increase the power and range of dorsiflexion and plantar flexion of the ankle. The resistance against which the patient worked could be varied. No patient showed an increased rate of mobilization of the ankle with this treatment. Again, in one patient a greater increase in movement was seen, when he was subsequently treated in a more advanced class. The increase in range of ankle movement, while he was operating the treadle, was 5° in 15 days; in the Early Legs class the increase was 12° in 16 days. In two patients there was rapid recovery of power of the calf muscles measured by ability to stand on the toes. However, there was not the same improvement in other functional tests, such as walking, which lagged behind the average recorded in Tables XXVI to XXVIII by as much as three to four weeks. In a further two patients treatment had to be terminated owing to the formation of an ankle effusion in one, and to the development of metatarsalgia in the second.

Physiotherapy A different approach to physiotherapy had been adopted in the two series. In Series B patients the commonest types of treatment were "faradism" to individual muscles (in 39 patients), and heat and massage (in 30 patients). Sinusoidal and faradic foot baths were used in the treatment

of oedema. In Series A patients the treatment of weak muscles by "faradism" was replaced by resistance exercises against springs (in 51 patients). "Faradism" was mainly used in the treatment of tendon lesions. Wax baths replaced radiant heat as the method of applying heat to the ankle (in 35 patients). Massage was employed in 36 patients but was confined to specific conditions; for example, it was used in the treatment of tendon lesions and ulcers, and the freeing of adherent scars.

The methods adopted for treating oedema also included massage, as well as the technique of "faradism under pressure":-

The patient lay supine on the examination couch with the limb elevated to between 60° to 70° , while the physiotherapist massaged the limb centripetally to increase venous drainage. The position was maintained with the knee supported with a pillow for treatment by "faradism under pressure". The metal stimulator pads were covered with lint in the customary manner, and soaked in warm saline; one pad was applied to the sole of the foot or, if the dorsiflexors were weak, to the dorsum of the foot. A second electrode was placed over the inguinal triangle. A rubber elastic bandage was firmly wound round the leg from the metatarsal-phalangeal joints to the mid thigh. Electrical stimulation was supplied by the Royal Air Force Type III stimulator, delivering a one-millisecond square pulse wave at a repetition rate of 50 per second. The stimulator output could be varied from 0 to 200 volts, and was automatically surged for this treatment at a repetition rate of 30 per minute. Muscle contractions indicated by the stimuli were reinforced by active contractions by the patient. The treatment was given for half an hour in the early morning and repeated in the mid-afternoon. The patient was instructed to keep the limb elevated as much as possible in the evening and to wear a crepe bandage between treatments. If the limb was persistently cold, wax therapy was given prior to faradism and massage. The limb was repeatedly dipped in wax at a temperature of 115° to 120°F (46° to 49°C) until a coating had formed about a quarter of an inch thick. The leg was then covered in wax paper and a muff, and elevated to 60° to 70° for 20 minutes, during which time the patient exercised the ankle and toes.

This technique was used to treat 22 patients with oedema. In 18 patients oedema was detected only with some difficulty after 10 days' treatment by this method. In the 4 remaining

patients oedema persisted for up to 8 weeks. These patients had arrived at the M.R.U. later than the third post-plaster week, and had had oedema for some weeks in spite of treatment elsewhere, which had included heat and massage or Unna's paste bandages. No patient failed to respond to the M.R.U. treatment, and a number of patients experienced considerable pain relief as well. No patient in Series A was confined to bed because of oedema, although it had been necessary on at least two occasions in the treatment of Series B patients, who did not have the benefit of this technique.

Spring resisted exercises were performed by the patient lying on his back with the spring attached by means of a toggle around the foot. Springs were most commonly used to develop supination and pronation, muscle contractions being performed for 15 minutes in each direction. As muscle power improved, the tension of the springs was increased from 10 lb. (4.5 kg.) to 30 lb. (13.5 kg.) at maximum extension. The results of treatment were difficult to assess, as in many cases improvement in muscle power was only slightly greater than that shown before treatment was started; in other cases the improvement was influenced by other factors such as treatment in a more advanced class. In 5 patients, an increase amounting to two grades in muscle power was recorded within 5 to 14 days of starting treatment; in contrast, progress was static in the corresponding period before treatment was started. In another patient the range of movement of supination and pronation improved by two grades, but the grading of muscle power remained static until he was advanced to the next class. One patient showed a definite improvement in the power of his calf muscles while exercising with calf springs, but there was a lag in the progress of walking similar to that seen in patients who operated a treadle in the occupational therapy department.

Although passive ankle movements are now generally considered as harmful, daily manipulation of the subtaloid joint by the physiotherapists produced relief of pain and improved inversion and eversion of the foot in the few patients in whom the joint remained stiff in spite of active exercises. Manipulation under a general anaesthetic was necessary in two instances. Manipulation of the metatarsal-phalangeal joints was employed with success in the treatment of metatarsalgia. "Faradic" stimulation of the intrinsics also relieved the pain in this condition when other methods had failed, but most patients responded to reduced weightbearing and intensive intrinsic exercises.

DISCUSSION

"The more one analyses disability the more one becomes convinced that the key to success is the restoration of muscle power". This concept has dominated the rehabilitation of injuries since it was propounded by Nicoll in 1941. Certain reservations must be made, however, before this principle can be applied to the rehabilitation of fractures of the tibia and fibula.

In the first place, only a small amount of exercise in plaster appears to be necessary to minimize the side effects of plaster immobilization. Before treatment at the rehabilitation centre had commenced, most of the patients in this study had been taught to perform toe exercises and quadriceps setting while in plaster for periods of up to half an hour per day. But treatment in plaster at the rehabilitation centre did not result in more rapid recovery than that observed when full time treatment had been delayed for up to two to three weeks after the removal of the plaster. This finding was supported by statistical analysis. There is a close parallel between this observation and those of Deitrick (1948), who studied the effects of immobilization in plaster casts on normal subjects. He found that even the very slight muscular contractions induced by an oscillating bed were sufficient to produce a marked reduction in the amount of muscle weakness and wasting, circulatory reaction and metabolic disturbances, which accompany immobilization.

Secondly, power reduction factors may seriously limit the development of muscle power by effecting a competitive block at interneural synapses to the passage of volitional and reflex impulses (Griffiths, 1943). In leg injuries the most important inhibiting factors are pain, fear and oedema.

The effect of pain on reducing muscle power was not studied quantitatively in the present survey. However, recovery was sometimes retarded by pain, when the exercise programme was advanced too rapidly. Pain also limited the use of resisted treadle exercises in the Occupational Therapy department. Spring exercises gave less trouble in this respect. Malkin and Parker (1943) abandoned the use of weight and pulley exercises in the rehabilitation of post-menisectomy patients owing to complaints of pain below the patellar ligament, which seemed to be more responsible for delay in improvement than weakness of the quadriceps muscles. Since then several weightlifting programmes had been devised (DeLorme, 1945; Gallagher and DeLorme, 1949; Zinovieff, 1951; MacQueen, 1954).

My experience of the last two techniques suggests that pain may also prove troublesome in any future study of progressive resistance exercises in lower leg injuries.

The effect of fear and the place of psychological treatment in the rehabilitation of injuries have been stressed by many authors (Moore, 1933; Houlding, 1941; Griffiths, 1943; Watson-Jones, 1955). Even normal volunteers immobilized in plaster for 6 to 7 weeks, are prone to psychological disturbances, such as feelings of insecurity and hostility, which occur not only during the immobilization period but may persist for several days after removal of the plaster (Brodman and Mittelmann, 1948). In the majority of patients, psychological disturbances settle rapidly in the atmosphere of the rehabilitation centre. However, there will always be a few individuals whose problems persist. This tendency appears to be more frequent in those patients suffering from post-traumatic osteodystrophy.

After nearly every fracture of the tibia and fibula some swelling of the leg occurs towards the end of the day. In this investigation clinical oedema was found after approximately 20 per cent. of both diaphyseal and malleolar fractures. From many years' experience it has been the practice in R.A.F. rehabilitation centres to limit supportive forms of treatment as far as possible. During this study a bandage of 'elastoplast' was applied over stockinet from the base of the toes to just below the knee for seven to ten days after the plaster was removed. A crepe bandage was then worn towards the end of the day if the leg swelled or earlier in the day if oedema was present. Many patients arrived at the centre wearing more rigid forms of support, such as 'viscopaste' bandages. This was not found to be satisfactory as it interfered with the performance of exercises. Moreover, in many cases considerable oedema occurred when the bandages were removed.

The incidence of oedema in those patients with diaphyseal fractures referred to the M.R.U. after removal of the plaster was twice as great as in those treated in plaster. Oedema was seen as frequently in those patients who arrived in the early post-plaster period as in those arriving later, but it was dispersed much more rapidly. Thus, the earlier treatment enables these patients to pass the tests of functional recovery at the same rate as those treated at the centre in plaster. Sir Reginald Watson-Jones has likened oedema to 'glue' which 'set' in the form of muscle and joint adhesions. Recovery is not delayed if oedema can be dispersed before it has 'set'. It is not surprising, therefore, that in those

patients arriving later in the post-plaster period, oedema was much more difficult to remove and contributed to muscle and joint stiffness.

For both diaphyseal and malleolar fractures, the groups of Series A patients arriving for rehabilitation in the immediate post-plaster period showed a consistently more rapid rate of recovery than the corresponding groups of Series B patients, (Tables X, XII, XVII.) The groups of patients arriving for treatment in plaster and in the late post-plaster periods showed an equal distribution of rates of recovery between the two Series. The more rapid recovery of Series A patients in the early post-plaster group is statistically significant ($p=0.05$), and it also seems likely that it was due to more rapid dispersion of oedema than in Series B patients. The method of dispersion used in Series A included a special regime of faradism under pressure, centripetal massage and ankle exercises with the foot elevated. It was not possible to undertake a controlled trial during this investigation to determine which was the most effective component of the technique.

The most important stage in the rehabilitation of both diaphyseal and malleolar fractures is the immediate post-plaster period. Further investigation of the use of physiotherapy techniques in this stage is indicated. The present study has shown that grouping of patients according to the time in plaster minimizes the differences between the types of fracture and enables recovery times to be compared. It is probably better to avoid including malleolar fractures in controlled trials as differences between the types of fracture are greater than observed between diaphyseal fractures. Methods of reducing the plaster time to below three months should also be considered. Watson-Jones and Coltart (1943) showed that by avoiding weight-bearing in plaster the proportion of patients showing clinical union within three months increased from 37.3 per cent. to 50.7 per cent. This finding was not followed up in the present survey but certain observations made by these authors were confirmed, namely, that distraction and disturbance of the fracture by delayed manipulation, delayed operation or wedging caused delay in union. There was no evidence that immediate open reduction resulted in delayed union. Strict adherence to the principle of rigid fixation of fractures of the tibial shaft results in bony union in eight weeks in the majority of fractures (Blockey, 1956). The splinting effect of the intact fibula is frequently ignored in assessing results of treatment. The present analysis has shown that when the tibia has been involved alone, the plaster can be removed a

month earlier than in a similar proportion of patients, in whom both bones have been broken.

The main feature of the classification of ankle fractures presented in this work is the division of the fibular fractures according to their relation to the inferior tibio-fibular ligaments. Localization of the fibular fracture site has also been used as a guide to mechanism of injury by Thomasen (1945) and Lauge-Hansen (1952). The commonest types of fracture encountered were due to violence in which lateral rotation predominated (isolated intertubercular fractures and bimalleolar intertubercular combined with posterior marginal fractures). Lateral ankle instability proved difficult to detect without the special radiological techniques recommended (Kleiger, 1956). In some patients apparently undisplaced fractures gave rise to symptoms of instability during mobilization, while, on the other hand, fractures in which considerable displacement had been left uncorrected, sometimes did remarkably well. Magnusson (1944) considered that a period of 29 days in plaster was inadequate to ensure healing of the anterior inferior tibio-fibular ligament in isolated intertubercular fractures of the fibula. In a follow-up of ankle fractures several years after injury, he found that the incidence of osteoarthritic changes on the radiographs was many times greater in the presence of pseudarthrosis of the anterior tibial tubercle than in those fractures in which it had apparently united. He considered the possibility of permanent lateral ankle instability to be greater when radiological evidence of pseudarthrosis was present. The mean plaster time for these fractures in Series A patients was 39 days and was probably nearer the ideal as patients immobilized for shorter periods took longer to recover. According to Magnusson radiological evidence of pseudarthrosis is not apparent for some months or years after injury and was rarely seen in this survey.

The activity of the calf muscles is as vital for the control of ankle joint function as the more familiar quadriceps muscle action for stability at the knee joint. The three components of calf muscle action, strength, endurance and co-ordination, appear to be of equal importance in normal activities. The ability to perform the progressive tests of calf muscle function (such as balancing on the toes of the injured leg and hopping) is a much more accurate indication of the progress of patients with lower leg injuries than measurement of joint range or of the power of individual muscles. The rather limited investigation of the

results of building up muscle strength or increasing endurance alone by spring exercises or treadle operation has indicated the limitations of this approach; the lack of co-ordination results in a persistent limp while walking or running at the stages in which the static tests of calf muscle activity suggest that the limp should have been eliminated. Griffiths (1943) also regarded the operation of a treadle as liable to hinder the return of the normal walking reflex by setting up inhibiting paths of reflex activity. Rehabilitation should progress most rapidly, when treatment corresponds as closely as possible to normal activities. Emphasis should be placed upon attempts at walking correctly on inclined planes as well as the level, and by free exercises and games devised to improve the natural spring action of the calf muscles.

Calf muscle action and oedema have been discussed separately for convenience, but they are in fact closely interlinked. The calf muscles act as a pump, which aids the dispersion of the oedema. The pump is sometimes inadequate, especially when weightbearing activities are advanced too rapidly; hence it has been customary at R.A.F. rehabilitation centres, in the early post-plaster period, to alternate weightbearing activity with periods of exercises with the limb level or elevated.

The question arises as to whether muscle weakness, oedema and joint stiffness are primarily due to a disuse (Watson-Jones, 1952), to phlebothrombosis (Ochaner and Landry, 1952) or reflex neurovascular disturbances (Fontaine and Herrmann, 1933; Casten and Betcher, 1955). In this survey the incidence of oedema remained constant as duration of plaster immobilization increased. Joint stiffness, however, increased in proportion to the plaster time. The presence of patchy decalcification in radiographs of the tarsus at the time of the removal of the plaster increased the probability of the subsequent development of oedema to nearly three times that expected when the radiographs were normal or showed only slight changes. This finding appeared to be independent of the duration of immobilization (apart from a few cases immobilized for over 6 months) or treatment at the M.R.U. in plaster. Trophic disturbances could also be anticipated in these patients if not already present at the time of the removal of the plaster. Certain patients appeared more liable to these disturbances than others and in a few the complete clinical picture of post-traumatic osteodystrophy developed. Blockley (1956) found that joint stiffness, oedema and osteoporosis are "caused by difficulty of the fracture consequent on the inadequacy of fixation and not by plaster fixation alone". He found that with rigid fixation

there is no pain. In contrast, Lucas-Championnière and Mennell (1911) claimed equally successful results by a method of treatment which was aimed at reducing pain by a special form of massage and maintenance of joint and muscle activity within a pain-free range. If disuse is considered to be primarily responsible for the patient's disability on removal of the plaster, then treatment depends on urging the patient to develop muscle power to its fullest extent both within and out of plaster. If, however, these changes are considered to be primarily reflex in character, resulting from inadequate immobilization in plaster, painful adhesions and the individual's response to interruption of normal proprioceptive mechanisms following immobilization, then a different treatment programme must be adopted. Thus, if rigid fixation of the fracture, avoiding the use of plaster of Paris, cannot be undertaken, it is important that we should understand how to treat the subsequent disturbances as effectively as possible. Certain physiotherapy techniques appear to be promising, especially in the early post-plaster period. Malkin and Parker (1943) considered that "the role of the medical man in rehabilitation is largely that of a medical whip and mental poultice." This attitude offers little scope for future progress and may well be unfair to the patient.

"Health is not received by words,
but by remedies fitly used."

AMBROISE PARE.

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CLASSIFICATION OF ANKLE FRACTURES

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